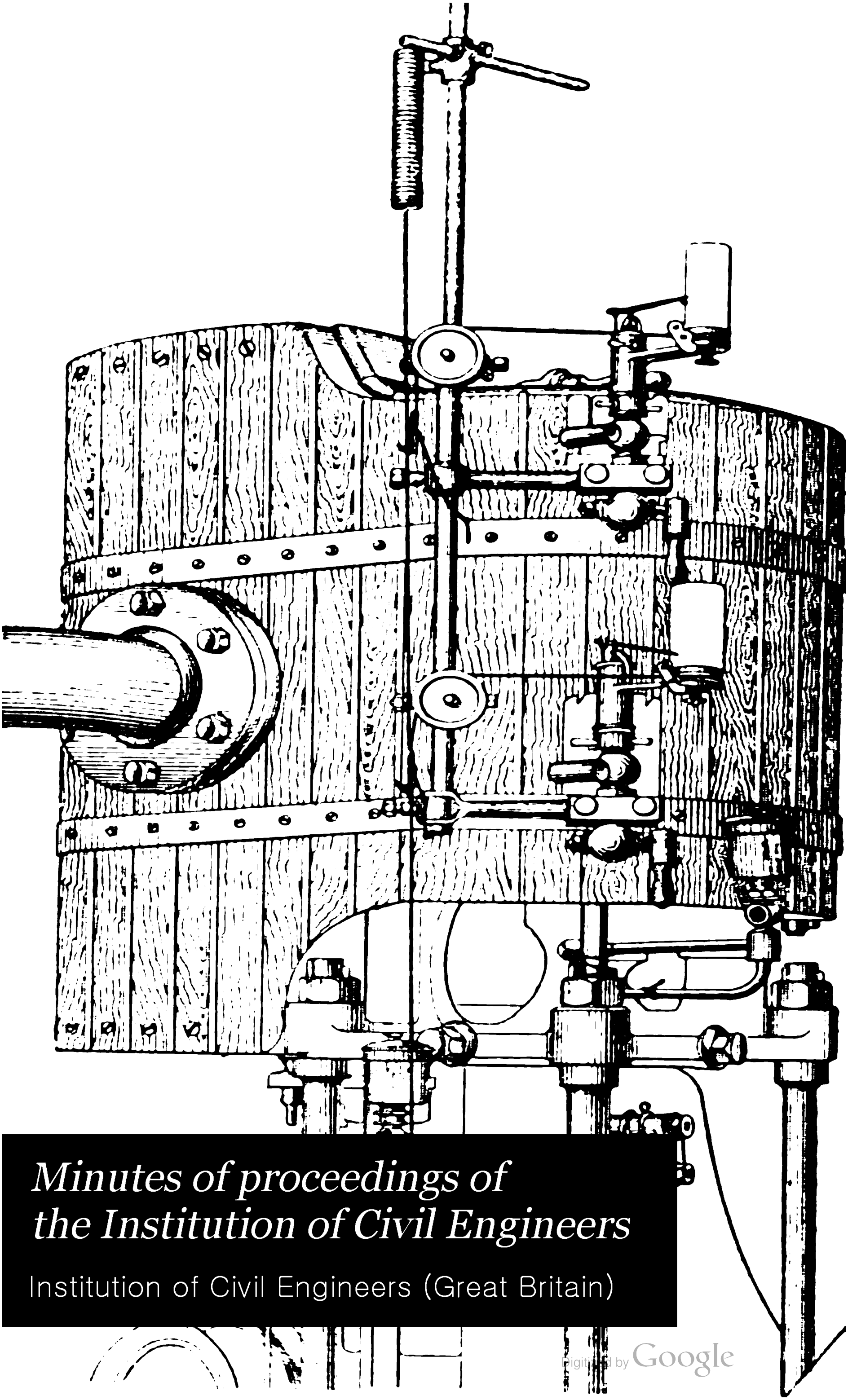

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. XCIX.

EDITED BY

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CORRIGENDA.

Vol. xcvii., p. 445, line 9, *for* "vol. xiv. 1888, p. 316" *read* "vol. xv. 1888, p. 816."

„ xcviii., p. 163, line 3 from bottom, *for* "2,000" *read* "1,200."

„ „ p. 411, Hall, Richard Thomas, *for* "died July 1889" *read* "died 21 August 1889."

„ xcix., p. 130, line 6 from bottom, in the second member of the equation, *for* "+" *read* "−."

THE INSTITUTION OF CIVIL ENGINEERS.

SESSION 1889-90.—PART I.

SECT. I.—MINUTES OF PROCEEDINGS.

12 November, 1889.

SIR JOHN COODE, K.C.M.G., President, in the Chair.

Sir JOHN COODE addressed the Meeting in the following terms, on taking the Chair at the first Ordinary Meeting after his election as President:—

At the time when I first became a member of this Institution, joining it in the year 1849 at the instance of my old and esteemed master, one of your former presidents, the late James Meadows Rendel, the idea of occupying the Presidential Chair certainly never occurred to me; that being the case when the total number upon the register of the Institution was about six hundred, how much greater must I esteem the honour you have now conferred upon me, when the number upon the Institution roll is within a measurable distance of five thousand!

Regarding the position of President of this Institution as the greatest honour to which any Civil Engineer can attain, I have accepted that honour with no light sense of the duties and responsibilities which it involves, and of apprehension as to my own shortcomings in the fulfilment of the various and important duties appertaining to it; but I am not a little encouraged by a confident hope and belief that I shall receive from my colleagues on the Council the aid and support, and from the members generally, the same indulgence they have extended to my predecessors in the Chair.

It rarely happens, between the presentation of the Annual Report of your Council, at the close of one session, and the commencement of another, that events occur in connection with the Institution of sufficient importance to call for any special remark from the President in his opening address. To omit, on this occasion, all reference to the exceptional and gratifying episode which occurred almost immediately after the close of our last sessional meetings,

would be to lay myself open to the charge of ignoring an important event, any reference to which, to use a colloquial expression, would be "conspicuous by its absence."

It need scarcely be said that I refer to the visit with which we have this year been favoured by an important detachment of our professional brethren from the United States of America.

For the first time in our history we have enjoyed the privilege and the pleasure of receiving, in a body, some two hundred and fifty members of the several American engineering societies, and it was, and is, a matter of no slight congratulation that every one of the engineering and allied bodies in the United Kingdom most cordially co-operated with us when, in accordance with our duty as the parent Institution, it was arranged that we should take the leading part in receiving and entertaining our American brethren.

Gratifying to ourselves as was this visit, it is certainly not less so to feel that their reception was highly appreciated by our friends from the other side of the Atlantic. In confirmation of this, let me quote from a letter written, early in August, by one of the foremost men of the party, announcing their safe arrival home. He said, *inter alia*: "The hospitality which we received at your hands was simply boundless; but what touched us still more deeply was the evidence of cordiality and friendship which was so apparent in all of the intercourse between the members of our party and our English friends from first to last. The memory will always be cherished and remembered."

Another of the leading members of the American party in writing quite recently says, "The day of the great Guildhall Dinner[1] is a famous date with us now: like every other member of our craft who came to see you last summer, I feel that you and your colleagues have placed me under such personal obligations as I shall probably never be able to repay, and that your grand old Institution has done for us what we shall not be prepared fully to parallel in a hundred years, even though the world does move so rapidly on this side."

When considering the question of a topic for this Address, it appeared to me that the experience gained during three lengthened professional visits to several distant and important parts of the British Empire might not unsuitably be drawn upon.

These visits, involving, as they have done, journeyings of more than 75,000 miles, and a close examination of some of the most important ports, harbours, and navigable rivers within many of our colonial possessions, have afforded me exceptional opportunities for

[1] 13th June, 1889.

becoming personally and intimately acquainted with such of the features, circumstances, and conditions connected with those Colonies, as are most interesting from the standpoint of a Civil Engineer.

The text of my subject on this occasion will therefore be :—

> "British Colonies as fields for the employment of the Civil
> "Engineer,—past—present—and future."

Keeping in mind the maxim of Horace—"Omne tulit punctum qui miscuit utile dulci"—it will be my desire so to combine what may be useful with that which I trust will be not altogether uninteresting, that you may not be wearied ere we have completed the lengthened tour that lies before us.

Whilst endeavouring to present to your view, from a professional standpoint, those features of the principal colonial possessions of the British Empire, which are of greatest interest to the Civil Engineer, I do not for a moment pretend to give an account of all the engineering works that have been, or are now being, executed within the Colonies mentioned. But, by the selection of some marked examples, it is hoped that additional interest may be created in the doings, past and present, of our brother Engineers in various parts of the world, and, at the same time, that there may be conveyed to not a few of those whose attention has not hitherto been drawn to the subject, a more exact idea than they may have heretofore entertained of the magnitude—the variety—and the vast resources of these possessions and their value to the Mother Country.

To make you better acquainted with the character and magnitude of the past and present labours of our professional brethren in those Colonies falling within the scope of the present examination will be a comparatively easy task; but he would be bold, indeed, who would attempt to assign limits to the future work of the Civil Engineer within the varied possessions of our great Empire. As regards this branch of the subject, it is well to adopt the course recommended by the sagacious author of the maxim, "Never prophesy afore you know;" it will therefore be my endeavour to place before you sufficient materials for judging of the vast fields of labour within those possessions still lying open to members of our profession.

And here, as germane to the subject, it may be remarked that the number of Engineers connected with this Institution who are engaged in British Colonies and Dependencies is by no means inconsiderable.

Very many of the most important works in the British Colonies have either been designed by, or submitted for the opinion of, leading engineers at home; there are, nevertheless, several of no

inconsiderable magnitude and importance that owe their inception to the genius of our Colonial brethren, and which have been brought to maturity under their fostering care. All honour be to them for the creditable manner in which they have, in so many instances, accomplished their tasks—oftentimes fulfilled under difficulties and drawbacks, not to speak of occasional dangers, of no slight magnitude.

Much might be said on what has well been called by an eminent writer, the "Expansion of England" within the last century; it cannot, however, be enlarged upon on this occasion. But, although I shall have a few comments to make upon this subject later on, your indulgence is asked for a few remarks which seem to be called for respecting certain marked differences in the character of our British colonial possessions.

And here naturally arises the question, What is a Colony?

Strictly speaking, a Colony is a country, or portion of a country, inhabited by a people who have gone forth from their Mother Land, and have made that country their home for the purpose of cultivating its soil or developing its natural resources; but still remaining as a people more or less directly under the government of the rulers of the land from which they or their ancestors may have originally emigrated. Such possessions, which are Colonies in the proper sense of the term, are hereinafter more particularly referred to.

It may be said, however, that certain British Dependencies are occupied and held solely, or almost solely, for strategic purposes "*in esse*" or "*in posse*," as, for example, Gibraltar, which is simply a strong fortress guarding the western entrance of the Mediterranean Sea; Malta, a naval arsenal of the first importance for refitting, repairing, and coaling our Mediterranean fleets; Cyprus, at the eastern extremity of the Mediterranean, which has been but recently acquired with a view to possible future military operations; and the little island of Heligoland, off the north-western coast of Central Europe, taken over from Denmark, presumably with a similar object in view; but neither of these two last named islands has been so utilized up to the present time.

Secondly; there are dependencies under the British Crown which are chiefly used as trading-stations, or entrepôts for the interchange of commerce with the surrounding countries that are consumers of English or European goods, but at the same time serve also as coaling depôts and stations for effecting repairs to steamers of the mercantile marine, or ships of Her Majesty's Navy; of such the most notable examples are Singapore and Hong-Kong.

Thirdly; there are Colonies which are exporters of their own produce on a large scale, and are known as "Plantation Colonies,"

e.g., the West India Islands, Mauritius, and Ceylon; and, fourthly, there are our Colonies proper, such, for example, as Canada, Australia, South Africa, and New Zealand.

In the first three of these classes the British element in the population is proportionately very small, but in the last-named class (with one notable exception) the whole community is, broadly speaking, of British origin, the exception being South Africa; for there—in the western part, which is generally called "the Cape," or sometimes, in other parts of South Africa, "the Old Colony"—a considerable proportion of Dutch settlers and of natives is found, whilst further east, in Natal, there are about forty thousand of our fellow-countrymen with four hundred thousand Zulus, who, I may say in passing, are physically a noble race, and, as a rule, law-abiding.

Running through much of that which will be presently adduced, there will be found a "key-note," as it were, that would seem to demand a remark or two before proceeding further. This key-note might have been described by the word "transportation" with Adam Smith, who says, "If the countries are near . . . transportation will be easy," but transportation has a disagreeable sound in connection with Colonies. Shakespeare speaks of "swift transportance;" but, taken on the whole, the subject which I am now dealing with, that is to say, the distribution, or the conveyance, or the movement of men and material things, is best represented by the single word "transport." May I here be permitted to express a doubt whether the importance and well-nigh ever presence of this factor in the works and labours of the Civil Engineer is fully realized by us all?

Wherever there is trade—and where is there not in this essentially busy age of ours?—there will of necessity be a demand for the means of transport; and where there is a demand for the means of transport there will equally be a demand for the works of the Civil Engineer.

It may be of interest to refer, in passing, to the statement of a well known writer on statistics, that whilst the population of the world increased by a little less than 10 per cent. in the decade between 1870 and 1880 the increase in transport within the same period was fully 53 per cent.

The connection is, I think, sufficiently obvious between "transport" and the several engineering works comprehended under the construction of railways, tramways, roads, canals, harbours, docks, steam-ships, locomotives, bridges, viaducts, aqueducts, tunnels, water-works, gas-works, sewerage works, drainage works, and

irrigation channels; but we may surely also include breakwaters, and lighthouses within this same category, for were there no passing ships transporting their passengers and merchandize, there would be no need for sheltering havens, or for guiding lights. Longfellow graphically illustrated this when he wrote :—

"Sail on . . . sail on, ye stately ships,
And with your floating bridge the ocean span.
* * * * * *
Be yours to bring man nearer unto man."

Although not perhaps very obvious at first sight, may it not be said with perfect propriety that electric telegraphs, whether above or whether below the surface of the land, or submerged in the depths of the sea, come under the same category? Apply a single test, by assuming for a moment the elimination from their operations of everything which may bear directly or indirectly upon the movement, conveyance, or, as has been previously said, "the transport of men and material things," and what would remain as the residue or balance? I venture to affirm, it would be so trivial in amount that no telegraphic line would be self-supporting, or anything approaching it; here then we see that this factor of "transport" pervades even the domain of electric telegraphy.

Is it too much to assert that harbours and docks assume a special importance in connection with our Colonies, and the subject of the transport of men and mercantile commodities both externally and internally?

As respects external trade, they form, as it were, the terminal links of those great chains of communication which, stretching across the "great and wide seas where go the ships," serve to bind together the Mother Country and her Colonies; or—to suggest another simile—they may be regarded as abutments to those floating bridges, which, spanning the great ocean highways, do really, in the words of the poet just cited, "bring man nearer unto man."

Further, as regards our larger Colonies, with their great extent of seaboard, as a matter of economy, in fact of necessity, the practice within them has been to extend the roads and railways from the sea-ports on the coast-line back into the interior, with the broad result that the land lines of communication parallel to the coast have been as yet, comparatively speaking, but little developed. As a consequence, a very large proportion of the traffic between different parts of the same Colony is sea-borne, and, from the force of circumstances, must continue to be so for a long

time to come. Hence it is that in most of our Colonies harbours and navigable rivers assume greater importance in the matter of transport than is generally assigned to them in the Mother Country.

Before entering upon descriptive particulars of some of the most important typical Engineering Works within the confines of the chief British Colonies, it will be expedient to consider the means of reaching them, and this naturally leads to what must always be to Engineers an interesting and important topic, that of oceanic transport by means of Steam Navigation, which is of great interest, indeed of paramount importance, in relation to my subject. The increase in the size, power, and speed, of steam-ships has been so remarkable since their first introduction, that it may be worth instituting a comparison between the vessels employed in trans-oceanic steam navigation at the time of its inception and at the present day.

It is by no means out of place to refer here to the steam communication between Liverpool and the United States, seeing that a not inconsiderable proportion of the passengers by that route consists of those who are passing from this country to her great possession, the Dominion of Canada.

The first crossings of the Atlantic by steam propulsion alone were accomplished by the "Sirius" of 700 tons, starting from Cork, and the "Great Western" of 1,340 tons, from Bristol, both reaching New York on the same day, April 23rd, 1838, a date which must always remain memorable in the history of Ocean Steam Navigation. The time occupied by the latter vessel on the outward voyage was fifteen days and six hours, but her return voyage to Bristol was made in fourteen days, notwithstanding that about twenty-four hours were lost by a stoppage at sea.

It was in this same year, 1838, that the English Government first invited tenders for the conveyance of mails to the American Continent by steam, whereupon the late Mr. Samuel Cunard, in conjunction with Mr. (now Sir) George Burns, made a tender to the Admiralty for the fortnightly transmission of mails between Liverpool and Halifax. This tender was accepted, and became the foundation of the now celebrated Cunard line. Their first vessel, the "Britannia," of 1,155 tons and 850 HP., left Liverpool on the 4th of July, 1840, and took fourteen days to complete the voyage. The passage between Sandy Hook (New York) and Roche's Point (Queenstown) is now not infrequently made in from six to six and a half days; in two instances it has been accomplished (by the "City of Paris") within six days.

The Peninsular and Oriental Company affords a typical and

striking example of the progress of Ocean Steam Navigation, more especially between the United Kingdom and our Colonies. A somewhat detailed reference to what has been done by it will, therefore, not be out of place.

The first contract with Her Majesty's Government for the conveyance of mails by seagoing steamers was that entered into in August 1837, by the company at that time called the "Peninsular." Inasmuch, however, as their steamers then ran only from Falmouth to Vigo, Oporto, Lisbon, Cadiz, and Gibraltar, this could only be regarded as an extended, but nevertheless a very important, coasting service. To this company, however, undoubtedly belongs the credit of having been the first to undertake a contract for the conveyance of mails from this country to, and from, foreign ports; the services, such as they were, had, up to that time been done by Admiralty packets at an enormous cost.

In the year 1840 the "Peninsular" was expanded into the "Peninsular and Oriental" Company, which entered into a contract with the English Government to convey the mails by steamer from England to Alexandria; subsequently it extended the service to India, despatching on this line the "Hindostan," of 2,017 tons, in September 1842. A further contract was undertaken by the same company in 1844, to carry the mails to Ceylon, Singapore, and Hong-Kong; and in March 1852 (after the failure of two other competitors) the Peninsular and Oriental Company commenced a service to Australia, which has been carried on in the most creditable manner in respect of punctuality, safety, speed, and, as regards passengers, with a degree of comfort amounting to luxury.

Fifty years ago the largest vessels of the Peninsular and Oriental Company (with a single exception) ranged from 600 to 800 tons each, the exception being the "Great Liverpool," of 1,311 tons and 464 HP. Twenty-five years ago there were very few of the vessels of this company of 2,500 tons, or of 2,500 HP. True, the "Himalaya," 3,500 tons, had been built by the company as far back as 1853, but was speedily sold to H.M. Government as being far too large for the commercial work of that date. The average tonnage of the fleet, of fifty vessels, is now upwards of 4,000 tons, with corresponding engine-power, the total being about 200,000 tons of the most costly description. The latest additions to the mail vessels of this fleet are ships of the type of the "Victoria," about 6,500 tons register, maintaining a regular sea-going speed of 15 to 16 knots on the 12,000 miles run from London to Australia.

The British Companies, owning at the present time what may, without exaggeration, be called fleets of magnificent steam-ships,

may be described in conventional language as "too numerous to mention;" certainly they are too numerous to be set forth in any detail here. Speaking generally, however, it is interesting to note that like the typical example (that of the Peninsular and Oriental Company) already cited, they have all, within so short a period as the last five or six years, made very rapid strides in the direction of increasing the size and power of their vessels.

By the increase in the size of the ships—by the diminished coal consumption and greater power arising from the adoption of the "compound" principle in the engines—by the reduction of weight in proportion to carrying capacity, consequent upon the adoption of steel—and by the extended application of steam and hydraulic power to many purposes in working the ships, and dealing with the cargoes (whereby the crews have not been increased in anything like the same proportion as the tonnage of the vessels)—from these several causes combined, all of which have been mainly due to the engineer and shipbuilder, such great economies have been effected as to bring about a reduction in the cost of Ocean transport, which is as remarkable as it is satisfactory.

Taking, by way of illustration, the cost of the freight of heavy goods such as unmanufactured iron, say to Sydney, on the eastern coast of Australia, a distance of nearly 12,000 miles, it appears that twenty years ago the freights by steamer for such goods ranged generally at about £25 per ton, whereas they were recently as low as 30*s*. a ton, or at the rate of only a little more than $\frac{1}{32}$*d*. per ton per mile.

Lest it should be imagined that the Suez Canal has been the principal cause, or, at any rate one of the principal causes, of this reduction, it should be explained that in this assumed case of Sydney the saving in distance by the Canal, as compared with the route by the Cape (although considerable in itself), is not more than one-ninth of the whole distance.

Before leaving this subject I should like to refer briefly to two recent but marked examples of modern passenger steam-ships. The first of these is the "Teutonic," belonging to the White Star line; this vessel is 582 feet (practically $\frac{1}{9}$ mile) in length, has a gross tonnage of 9,685, and is provided with accommodation for one thousand two hundred passengers, three hundred being first class. She is intended, by arrangement with the Admiralty, to carry in time of war twelve 4·7-inch quick-firing guns, having a maximum range of over 5 miles, and eight 1-inch four-barrel Nordenfelt quick-firing guns; she may therefore be regarded as a combination of, or a "cross" between, the peaceful "Greyhound of the Ocean" and the pugnacious "Bulldog of the Sea."

The other example is the "City of Paris," belonging to the Inman and International Steam-ship Company. This is the only vessel which, up to the present time, has made the voyage between Sandy Hook and Roche's Point in less than six days; her mean speed on that voyage in May last was 20·6 knots, equal 23·73 statute miles per hour. Her runs on three consecutive days were 504, 505 and 511 knots, or a little over 580½, 581¾ and 588¾ statute miles, respectively. She has again accomplished the voyage between Sandy Hook and Roche's Point within six days, her actual time on arrival last Tuesday having been five days twenty-two hours, fifty-seven minutes, as compared with five days, twenty-three hours, thirty-eight minutes on a previous voyage; in round numbers she has, in six voyages, run 17,000 knots at an average rate of nearly 20 knots (23 statute miles) per hour. This fine vessel is of 10,500 tons, and 18,000 HP. (*i.e.* eight times the tonnage and forty-five times the HP. of the "Great Western"); she has twin screws, and two distinct sets of triple-expansion engines. A forced draught is supplied to the fifty-four furnaces, in which is consumed a ton of coal every five minutes, when she is under full steam. Her boiler-tubes measure upwards of 13 miles in length, and she has on board thirty-two auxiliary machines worked by hydraulic power.

Compare this "City of Paris" with the "Great Western," of 1,340 tons, 400 HP., upon which the newspapers of the day remarked, that when in the Thames, she was "crowded with visitors who were astonished at her magnificent proportions and machinery."

Of the "Great Britain," 3,440 tons, it was said that "the excitement caused by her arrival at Blackwall was very great; that thousands of persons flocked to see her, and that she was honoured by a visit from Her Majesty the Queen, and H.R.H. Prince Albert."

Nowadays the arrival in the Thames or Mersey of a vessel twice or thrice the size of the "Great Britain," or six times larger than the "Great Western," is a matter of such frequent occurrence that it fails to excite public attention.

Interesting as the remarkable advances have been in ocean steaming since its commencement to all who view them from a general standpoint, they are particularly so to those of us who are old enough to remember, not only the birth and infancy of this great enterprise, but also the confident and reiterated predictions of failure and disappointment which it was said must result from the attempt to cross the Atlantic by steam-power alone—an attempt which, in some quarters, was regarded, and freely characterized, as an act bordering upon lunacy on the part of its promoters and advocates.

It would be idle to speculate upon the future progress of steam-navigation, but I may mention that some of our professional brethren in the United States are confidently predicting for it a thorough revolution, through the adoption of the by no means new idea of expelling a jet of water from the stern of the ship. Hitherto the trials seem to have been limited to jets of water of large area at comparatively low velocities; but it appears that a new departure is intended, and is to be tested in a boat now being built for trial in New York Harbour, the propelling jet from which is to be only $\frac{3}{4}$ inch in diameter, delivered under the pressure of 2,500 lbs. to the inch. As to the outcome of this experiment, should it be attended with the success which the promoters contemplate, we may confidently rely upon hearing more in due time.

Knowing the tediousness of bare statistics, the figures I shall place before you will be as few as possible compatible with the attainment of the object I have in view, which is to convey, as far as may be in my power, the most correct idea of a few of the chief engineering works which have been, or are being, carried out in British Colonies, and the scope which exists in those Colonies for the future employment of the Civil Engineer.

I have compiled the following table containing a few notes, which may be regarded as embodying so many standard measures whereby you may readily and accurately gauge the relative magnitude and importance of some of the facts that will be presented to you, and thus, it is hoped, a correct comparison will easily be made between "Great" and "Greater Britain" in respect of many matters which cannot well be otherwise than interesting:

Great Britain.

Length, extreme north and south, measured on a meridian	miles	600
Area	sq. miles	88,000
Population	total number	33,000,000
"	per sq. mile	375
Death-rate	per 1,000 per annum	17·8
Railways	1 lineal mile to sq. miles of territory	4·4
River, longest course (Thames)	miles	200
" largest catchment basin (Humber)	sq. miles	9,400
Lake, area of largest (Lomond)	"	30
Coal-fields, total area	"	5,100

The limitation to Great Britain alone, without comprehending the sister island, must not be interpreted as indicating what in America would be called a "proclivity" towards the severance of that which is now, and it is to be hoped ever will remain, the United Kingdom of Great Britain and Ireland; this limitation has been adopted solely because we shall thus have a standard that will be more familiar to most than if two islands were taken together, and one whereby, as being more simple, a comparison can be more readily and accurately made as we proceed.

It will now be desirable to speak in some detail of British Colonies, and particularly of such of their features and characteristics as have a bearing upon the subject under special consideration, giving, Their position, general configuration, and physical features; Area and population; Climate; Industrial products and mineral wealth; and, Public Works, whether already executed, in progress, or contemplated in the immediate future.

Commencing with the Western Hemisphere, it will be proper first to deal with what was originally a group of separate provinces on the American Continent, but which, since May 1867, have been federated under the title of the "Dominion of Canada."

CANADA.

Canada is larger than any other of the Colonial Dependencies of the British Empire; it extends across the entire Continent from the Atlantic to the Pacific Ocean, it is about 3,500 miles from east to west, and 1,400 miles from north to south. The total area of the Dominion is 3,610,000 square miles.

The population is 4,875,000, or 1·35 per square mile, the average death-rate in the towns being 25·17 per 1,000.

A special geographical feature in the Dominion is the general distribution of fresh water by its numerous lakes and rivers, which cover no less than 140,000 square miles—nearly 52,000 more than the entire area of Great Britain. The lakes are said to contain more than half the fresh water of the globe.

The climate is healthy and invigorating; owing to the fact that it extends over no less than 20° of latitude, it has a great range of temperature, nevertheless the extreme dryness of the atmosphere makes both cold and heat less acutely felt than might be expected from the great range of the thermometer.

An average winter lasts about four and a half months; and, although the spring may begin two or three weeks later than in

England, the warm sunshine and rain are so favourable in the Dominion that the crops of the two countries are almost equally advanced by the middle of July. It seems indisputable that the climate of Canada as a whole is not inferior to that of England, and that in summer the weather is not surpassed in the most favoured parts of Europe.

As is generally known, the Rocky Mountains, or "Rockies" as they are sometimes called in common parlance, are the principal mountains; they extend from the Arctic Ocean to the United States; and contain the highest points in the Dominion, the chief of which are Mount Hooker, 16,750 feet, Mount Brown, 16,000 feet, and Mount Murchison, 15,000 feet; there are several others of nearly the same height. The Canadian Pacific Railway crosses this range, through the "Kicking Horse Pass," at an altitude of 5,300 feet above sea-level.

Mineral Wealth.—Nearly all minerals of value exist in greater or less quantity in the Dominion; its natural wealth is, to all intents at present, an unascertained quantity; many parts of the country where minerals are known to be are as yet practically unexplored.

In the North-West Territories, the coal-bearing area has been estimated at 65,000 square miles, and the quantity of fuel, known to underlie some portion of this area, at from 4,500,000 to 9,000,000 tons per square mile. This coal varies in quality from lignite to bituminous.

Canals, &c.—The system of inland navigation is the largest in the world. The St. Lawrence system alone, in conjunction with the great lakes, extends for 2,260 miles, viz., from the Straits of Belle Isle to Port Arthur, at the head of Lake Superior. When it is considered that by this means unbroken water communication is afforded to Port Arthur and Duluth from Liverpool, a total distance of 4,618 miles, the importance of this system, and the necessity for its thorough maintenance, will be understood.

To mention only two other of the chief canal systems of Canada, that which connects Montreal and the city of Ottawa, and the Rideau which, in conjunction with the Ottawa system, affords communication between Montreal and Kingston, a total distance of 246 miles. The lockage on this latter system, not including that of the Lachine Canal, is 509 feet, viz., 345 rise and 164 fall, and the number of locks is fifty-five.

The Richelieu and Lake Champlain system, or Chambly Canal, extends from the junction of the Rivers St. Lawrence and Richelieu, 46 miles below Montreal, into Lake Champlain, a distance of

81 miles. There are ten locks and a rise of 79 feet. By the Lake Champlain Canal communication is obtained with the Hudson River, and thence to New York, to which place from the boundary line is a distance of 330 miles.

Railways.—The total length of railways in the Dominion may be taken at 12,500 miles. The proportion of the mileage of railways to the area of any country is, broadly speaking, a measure of its development; applying this standard, it appears that the area of territory in the Dominion per lineal mile of railway is in the proportion of 290 to 1; applying the same standard to Great Britain, the proportion is less than 4½ to 1. The expenditure on these railways up to the end of 1887 was no less than £142,500,000.

Although completed thirty years ago, the Victoria Bridge across the River St. Lawrence still stands out prominently as one of the finest engineering works of the last half century. The tubular girders in this bridge are 6,592 feet, just 1¼ mile in length, supported on twenty-six piers, founded in a current having an average velocity of 7 miles an hour; the pressure against these piers during the break-up of the ice is enormous.

An engineering work, having a very important bearing upon the commercial prosperity of the Dominion as a whole, and most certainly of the City of Montreal in particular, was completed, and formally opened, exactly twelve months ago; I refer to the ship-channel in the St. Lawrence, having not less than 27½ feet of water, whereas the depth originally in some portions of the channel was only 11 feet; merchant steam-ships of the largest class are consequently now able to reach Montreal.

Three large graving-docks have recently been constructed in this Colony; one at Esquimalt, in the province of British Columbia, 451 feet long, 55 feet wide at the entrance, with 24 feet 6 inches and 26 feet 6 inches of water over the sill at neap- and spring-tides respectively. The graving-dock at Halifax, in the province of Nova Scotia, is 540 feet long, 85 feet wide at the entrance, with 29 feet and 30 feet of water over the sill at neaps and springs respectively. The "Lorne" graving-dock, opposite Quebec, is 550 feet in length, with a width of 62 feet at the entrance, and a depth over the sill of 26½ feet at high-water of spring-tides.

A ship railway, 17 miles long, is being constructed for the transport of vessels across the narrow isthmus which connects Nova Scotia with New Brunswick. It is intended for vessels up to 2,000 tons with full cargo; by it a saving in distance of from 500 to 700 miles will be effected, and the risks of navigation

outside Nova Scotia along a notoriously dangerous coast will be avoided. This work has been subsidised by the Government of the Dominion of Canada, and is expected to be available for traffic about the end of 1890.

Taking a southerly course from the Dominion of Canada we reach the

West Indies.

The harbour of Castries (the chief town of the Island of St. Lucia) will be certainly one of the best in the West Indies when the works now in progress are completed. A fine quay has recently been constructed within this harbour, having a depth alongside of 27 feet at low-water, which admits of the mail steamers obtaining access at all times. The coral shoals in certain parts of the bay are being dredged to a like depth, the greater part of them having already been removed. Castries has been selected as the chief coaling station for the British fleet in the West Indies. This harbour will become of still greater importance in the event of the completion of either the Panama or the Nicaragua Canal; the latter project being under the auspices of the United States Government, its prospects have considerably improved of late.

Returning to Europe, mention may be made of the little island of

Heligoland,

as being the smallest of all the British Possessions on the globe, and the northernmost of them in the Eastern Hemisphere. Lying about 15 miles off the north-west coast of Germany, and between the Elbe and the Weser, it has been described as "The property of England, and the envy of Europe."

Its area being about ¼ square mile, it will be well understood that it does not possess any feature of engineering interest, unless it be that between the landing-place on the sea beach and the town on the table-land of the island, 170 feet above the sea, the communication, formerly gained by a flight of some two hundred steps, is now effected by a lift worked by steam-power. There is not a single horse on the island, and it was stated at the time of my visit, about six years since, that of the inhabitants, who are of Frisian origin, very few have ever seen one.

Proceeding southward: inasmuch as the British Possessions within the Mediterranean sea, viz., Gibraltar, Malta, and Cyprus,

have been acquired, and are held, for strategic purposes only, they do not fall within the scope of my address.

Still continuing southward, and passing by the "West Africa Settlements" on the Atlantic seaboard, the "Gold Coast Colony" in the Gulf of Guinea, and "Lagos" in the Bight of Benin, also the islands of "Ascension" and "St. Helena," which do not possess any notable features of engineering interest, the next important Colonies I shall deal with are those in

South Africa.

At the present time there are only two British Colonies (recognized as such) in Southern Africa, viz., the southernmost portion of the Continent, generally known as "The Cape of Good Hope" (sometimes as the "Cape Colony"), and "Natal," which lies to the north-east.

By a Charter just granted, authority has been given by the Imperial Government to the "British South African Company," to develop the resources of an enormous tract of country northward of the Cape Colony (to be called "British Zambesia"), four times larger than Great Britain, and one-third greater than Germany.

Much of this country is described as being "fabulously rich in precious metals, having forests alternating with cultivable land, the whole intersected with unfailing streams, and the climate an ideal one for Europeans"; it is held by many, and with apparently good reason, that "Ophir," whence the gold used in the Temple of Solomon at Jerusalem was obtained, lies within this tract of country; that it was inhabited at some prehistoric period is proved by the existence of the remains of forts and furnaces. One of these ruined structures is 450 feet in diameter, its walls being still 30 feet high; they are 15 feet thick, and built of granite, hewn into blocks about the size of a common brick, and put together without mortar.

Cape Colony.

This name is derived from the Cape or head of the great promontory which forms the western side of Simon's Bay, well known as the chief naval station in the South Atlantic Ocean.

This, the southern and most important British Colony on the African Continent, is bounded on the west by the Atlantic, and on the south by the Indian Ocean; it has a coast line of about 1,100 miles, and an area of 213,900 square miles. The population was estimated at the end of 1887 at 1,377,000, or in the ratio of 6·4

per square mile—the population of Cape Town and suburbs being about 70,000.

The climate is favourable to Europeans, the heat never oppressive, and the winter mild and delightful; the average rainfall in the Cape Town district is 22·83 inches.

Several mountain ranges cross the country in irregular lines, and, proceeding inland, in successively increasing altitudes, from Table Mountain, 3,852 feet high, near the southern seaboard, to the Drakensberg Range, 10,000 feet high, on the borders of the adjacent Colony of Natal.

The Colony is well intersected by rivers, the principal of which is the Orange River on the north.

The chief industrial products are wool, wine, wheat, barley, oats, tobacco, and maize; there is a flourishing industry in the breeding of horses, cattle, goats, ostriches, and sheep; minerals are widely spread and of enormous value. As an instance; the Cape Copper Mining Company, with a capital of £160,000, has paid to its shareholders close upon £1,400,000, thus having returned its capital nearly nine times over, and has accumulated reserves, in the shape of estates, buildings, works, and cash, to the amount of more than £260,000. This Company has built and owns a railway nearly 100 miles in length, which crosses, in its course, a range of mountains rising over 3,000 feet above the sea-level, thus connecting the principal mine with Port Nolloth, whence the ore is shipped direct to England.

Gold and diamonds are produced in large quantities; the mining of these during the last few years has found profitable employment for capital to the extent of many millions sterling.

From that part of the Colony known as Griqualand West, there have recently been exported annually, diamonds to the value of from £3,500,000 to £4,500,000 sterling; the total export of diamonds from the Colony up to the present time has been upwards of £46,000,000. It has been stated that one firm alone purchased nearly the whole of a single month's output of the Kimberley and the De Beers' Mines, for £250,000 sterling; the purchase being a large bucketful of rich stones weighing about 250,000 carats or 150 lbs. The Kimberley Central Company's Mine is worked as an open cutting or pit, to a depth of 450 feet, and by shafts and "levels," or headings, to a further depth of 150 feet.

The public works completed and in progress comprise about 1,700 miles of railway, constructed at a cost, up to the end of 1887, of £14,250,000; this length gives 1 lineal mile to 126 square miles of territory. Also an inner and outer harbour at Table Bay,

under Table Mountain, having areas of 8½ acres and 62 acres respectively, and a depth of from 24 feet to 36 feet at low-water. A sheltering breakwater at present about 3,400 feet long, a graving-dock, 500 feet long, lined with local granite, with an entrance 68 feet wide, and depths over the sill of 21 feet and 26 feet at low and high water respectively.

The inner basin and graving-dock were excavated out of the solid rock, the depth of cutting below the surface varying from 24 feet at the shore line, to 65 feet on the landward side.

It may be remarked in this connection, that the harbour works, when completed, will convert Table Bay into a station of the greatest value for the docking, repairing, refitting, and coaling ships of Her Majesty's Navy, and one of vital importance should this country unhappily be involved in war.

At Port Elizabeth, in Algoa Bay, two substantial iron jetties have been erected, together about 1,700 feet long, having lines of railway in connection with the general system of the Colony, and furnished with steam-cranes for dealing with cargo; water-works for the supply of the town and district have recently been constructed.

The improvement effected by the breakwater and training-banks at East London, supplemented by the use of a sand-pump dredger, now enables vessels drawing 15 feet of water to enter and leave the river, whereas formerly, in consequence of the entrance being closed by sand, the whole of the traffic between vessels in the roadstead and the shore, was, of necessity, carried on by boats warped in and out through a continuously-breaking surf. Still further deepening is in progress.

Similar improvements have been effected by works at the Kowie River, now known as Port Alfred.

The Colony of Natal

is situated on the East Coast of South Africa; it has an area of 18,750 square miles, and a coast-line on the Indian Ocean of 170 miles. The population, more than four-fifths of whom are Zulu Kaffirs, is estimated at 477,100, being in the ratio of 26 inhabitants to 1 square mile. Pietermaritzburg, the capital, has a population of 14,000, and Durban, the seaport, 18,000.

The climate varies, but is usually mild, cool, and bright; the average rainfall on the coast is 40 inches, and less inland.

The Colony is bounded on the west by the Drakensberg range of mountains; and is traversed by numerous rivers, but none of these are navigable.

The chief exports are gold, which is being raised in large and increasing quantities, wool, sugar, hides, maize, hair, arrow-root, and ostrich feathers; the main industries, however, are mining, agriculture, and the rearing of cattle and sheep. Tea, tobacco, sugar, and coffee are grown.

There are 220 miles of railway open, all constructed and worked by the Government, equivalent to 1 mile of railway for each 86 square miles of territory. These railways up to the end of 1887 had involved an expenditure of £2,750,000. The harbour of Durban has recently been much improved by a breakwater and pier, which are not yet finished. The port possesses an exceptional advantage in the peculiar configuration and size of a large inner bay, having a tidal capacity of 25,000,000 cubic yards. This bay is, in effect, a large scouring reservoir, which will discharge the above-mentioned quantity of tidal water between the breakwater and pier when completed, at a velocity of about 2 knots per hour, thereby preventing the accumulation of sand in the entrance.

North-east of Natal, some 5,000 miles across the Indian Ocean, is the beautiful and interesting island of

CEYLON,

which has been likened to "a pearl on the brow of India," and described by one who for many years was officially and honourably connected with it, as "bright with the foliage of perpetual spring."

On a near approach to the coast, attention is arrested by a remarkable belt of cocoa-nut palm-trees, and, on entering the now busy harbour of Colombo, a scene is unfolded which vividly realizes the accuracy of the poet's description:—

> "The cocoa with its crown of spears
> Stands sentry round the crescent shore."

In this connection it may be stated that for a length of 80 miles north, and for a similar distance south of Colombo, the coast is fringed with a continuous belt of cocoa-nut palms, from ¼ mile to several miles in breadth, covering an area of 500,000 acres, and having a capital value of £12,500,000.

This Colony is 266 miles long from north to south, and 140 miles wide at the broadest part, its area being 24,700 square miles. The population, including native races and coolies from India, is about three millions, or in the ratio of 121 inhabitants to each square mile of territory.

The climate of Ceylon is, of course, tropical, but comparatively healthy, the heat being less oppressive than on the mainland of India. The annual rainfall varies from 30 to 230 inches according to locality, and the average death-rate was 24·0 per 1,000 for the year 1887.

The Colony is exceedingly fertile, raising in abundance, tea, coffee, rice, tobacco, cocoa-nuts, and various kinds of spices.

There are but few, if any, more remarkable instances of the creation and rapid expansion of an industry than that of the cultivation and preparation of tea in the island of Ceylon. The failure, through disease, of the coffee crops about ten years ago has proved to have been "a cloud with a silver lining," dark as that cloud was when it temporarily overshadowed the island. Commencing with the insignificant production and export of only 15 lbs. sixteen years ago, it has since advanced in rapid progression year by year, having attained the high figure of 32,500,000 lbs. in 1888. The annual export for the last nine years has been as under:—

	Lbs.
1880	115,000
1881	311,000
1882	621,000
1883	1,600,000
1884	2,300,000
1885	4,400,000
1886	7,800,000
1887	13,500,000
1888	32,500,000

Of railways, all owned and worked by the Government, there are 180 miles, giving a proportion of 1 lineal mile of railway for each 137 square miles of country; the net profit from these railways has now risen to nearly 11 per cent. on the outstanding capital, which amounted at the end of 1887 to £3,000,000.

Large works are in progress for the water-supply of Colombo, and the surrounding district.

At Colombo a breakwater has been constructed, 4,200 feet long, sheltering 500 acres of harbour, the greater portion having a present depth of more than 26 feet, which is being increased to 28 feet and upwards.

Colombo Harbour is very largely used for the transhipment of goods and passengers between Europe, the Bay of Bengal, Straits Settlements, China, Japan, and the Australasian Colonies.

East of Ceylon, at the southern end of the Straits of Malacca, is

Singapore,

the capital of the Straits Settlements. This Colony bears the designation of "the Golden Chersonese." Singapore, as previously intimated, is a great entrepôt for the interchange of commerce; the trade of the port is enormous, and increases year by year. The transhipment of goods is carried on in the roadstead by means of cargo boats, called "sampans," varying from 2 to 5 tons, and larger craft ranging from 10 to 60 tons. About two thousand sampans are moored nightly in the lower reach of the river or pool, where they derive such an amount of shelter from the natural configuration of the shores, that no artificial works for protecting them are necessary.

There is in course of execution immediately to the southward of the city a sea-wall 3,000 feet in length. The land reclaimed in the rear of this wall, being immediately contiguous to the business part of the city, will be a source of revenue to the Government. Some of the landward portion of it has already been disposed of at very satisfactory prices.

Within the broad, deep, and well-sheltered channel, lying to the south-west of the city, and known as the "New Harbour," there is a practically continuous length of 3 miles of frontage occupied by wharves, docks, and mercantile establishments, at which the largest ocean steamers are accommodated.

The next Colony, in a northerly direction from Singapore, is

Hong-Kong,

an island situated in the China Sea. The harbour, which lies on the north side of the island, is sheltered by the mainland of China. Like Singapore, Hong-Kong is an entrepôt for the interchange of traffic. The sea-front of the city of Victoria, which is the capital of the Colony, is 4 miles in length. Numerous jetties project from this sea frontage for the landing and loading of goods.

Hong-Kong is occasionally visited by typhoons of a most violent character, and sometimes by very heavy rainfall; particulars have just reached me of a storm at the end of May of the present year, when 33·11 inches fell in thirty-eight hours, which included the very remarkable fall of 27·44 inches in twenty-four hours.

An entirely new and substantial sea-wall, rather more than 1¾ mile in length, and founded in about 30 feet of water, is about to be constructed parallel to, and 250 feet seaward of, the existing wall. Between these two walls there will be reclaimed an area of 60 acres, whereon high-class buildings are to be erected.

The cost of this wall and reclamation is estimated at about half a million sterling, and arrangements have been made whereby the outlay will be considerably more than recouped.

We have now to make a voyage of 6,000 miles down the South Pacific Ocean to the Australasian group of Colonies. The first of these which we shall visit is

New Zealand.

The Colony of New Zealand, which is situated about 1,200 miles south-east of Australia, and is bounded on all sides by the Southern Pacific Ocean, consists of the three islands formerly known as the "North," "Middle," and "South"; the size of this latter, however, is such in proportion to that of the other two, that it would be almost as appropriate to speak of Great Britain and the Isle of Wight as the north and the south islands. But reason has prevailed, and the present nomenclature runs far more properly, the "North," "South," and "Stewart" Islands. The north and south islands of New Zealand are separated from each other by the waters of "Cook Strait," about 140 miles long, 15 miles wide near the south-east end, and 100 miles wide at the north-west end. Foveaux Strait, about 40 miles long, and 20 miles wide, divides Stewart Island from the South Island.

New Zealand has been well called the "Britain of the South"; it formed one of the great discoveries of the justly-renowned Captain Cook, of whom Baron Hübner graphically writes:—"I am astonished at the number of lands he was the first to see and reveal to the world, the fabulous and previously unknown seas he traversed, and the difficulties and dangers he encountered."

New Zealand is thus spoken of by the author of "Greater Britain":—"Placed in the very track of storms, and open to the sweep of rolling seas from every quarter, exposed to the waves that run from . . . . South Africa and from Cape Horn, the shores of New Zealand are famed for swell and surf, and her western rivers for the danger of their bars."

All those who have had personal experience of the New Zealand shores, and the river entrances of the west coast more especially, will agree that this picture is by no means overcoloured.

The combined area of the three islands is 104,000 square miles, thus distributed:—

	Miles.
North Island	45,687
South Island	57,313
Stewart Island	1,000
	104,000

The coast line of the two principal islands combined is nearly 3,000 miles.

The white population of New Zealand, at the end of the year 1887, was estimated at 603,360, or at the rate of 5·79 per square mile, and the average death-rate for that year 10·28 per 1,000; this is a lower death-rate than in any other of the Australasian Colonies, and not much more than half that of Great Britain.

As the Colony extends over more than 13° of latitude, and is influenced greatly by the two mountain ranges which—interrupted by Cook Strait—run longitudinally from north-east to south-west through the whole length of the two larger islands, the climate varies greatly. Although not subject to extreme heat or cold, the changes from sunshine to rain, and from calms to gales, are such as to prevent its being said that there is any wet or dry season in the course of the year.

In the South Island the Southern Alps stretch parallel to the west coast for a distance of nearly 200 miles, many of the higher portions of them being covered with perpetual snow; the loftiest peak of this grand and beautiful range is Mount Cook, 12,350 feet high. Viewed from the sea, at a distance of 15 miles, the sight is a magnificent one, and leaves an impression never to be forgotten by any lover of mountain scenery.

In connection with the subject of mountains in New Zealand, mention of "Mount Egmont," which stands close to the south-western extremity of the North Island, must not be omitted. This is the most remarkable mountain in the Colony. It rises from almost a plain to the height of 8,300 feet, in the form of a very perfect cone, having a base 30 miles in diameter, with its summit, which is an extinct crater, covered with perpetual snow.

The largest lake in New Zealand is Lake Taupo, near the centre of the North Island; it has an area of 200 square miles, with an unknown depth. The largest river is the Molyneux or Clutha, in the South Island; after a course of 130 miles, during which it receives the waters of three large lakes, it debouches into the sea near the south-east extremity of the island.

The coal-fields known to exist at the present time are nineteen in number, their total area is 760 square miles. The quantity, so far as at present ascertained, is estimated at 450,000,000 tons. The bituminous coal, found on the west coast of the South Island, is declared by engineers of local steamers to be fully equal to, if not better than, the best descriptions from any part of the world.

The wonderful escape of H.M.S. "Calliope" during the hurricane at Samoa, when her engines were tried to the very utmost, has

been attributed by her captain and the people of New Zealand—apparently with good reason—to the superior quality of this coal, which was being used at the time.

In this Colony 1,750 miles of railway were completed up to the end of 1887, giving 1 lineal mile of railway to 59 square miles of territory; the expenditure up to the same time was £14,750,000.

Breakwaters and training-banks are being constructed for the improvement of the River Buller entrance at Westport. Since these works have been in progress from 5 feet to 6 feet extra depth has been obtained, and vessels drawing 16 feet now enter and leave the river.

A new graving-dock has lately been completed at Auckland 500 feet long, 80 feet wide in the entrance, having 33 feet depth of water over the sill at spring-tides.

Since 1880 breakwaters and training-banks have been in progress at Greymouth, the entrance to the Grey River, and they are now nearly completed. The river has been deepened about 9 feet, and vessels drawing 16 feet freely enter. Dredging has been dispensed with for the last four or five years. The trade of this river has more than doubled since the commencement of the works.

A breakwater, which acts also as a training mole is being constructed at Otago Harbour entrance, by which the depth of water over the bar has been greatly increased, so that mail steamers regularly enter and leave the port.

A harbour has been created at Lyttleton, near the city of Christchurch, in the provincial district of Canterbury, by the construction of two breakwaters, which enclose an area of about 112 acres, in which there are several jetties and wharves, having together a length of berthage of 11,000 feet, with lines of railways in connection with the general system of the island. The depth within the breakwaters varies from 19 feet to 25 feet at low-water.

Turning westward we come to the island of

Tasmania,

which lies about 150 miles to the south of Victoria, the southernmost part of the Continent of Australia. It is separated therefrom by Bass Strait, which connects the Pacific with the Great Southern Ocean.

Tasmania has been supposed by some to have originally formed part of Australia; there certainly is a very remarkable correspondence between the configuration of the northern coast of Tasmania and the southern part of Australia, directly opposite to which it is situated. Its extreme length from north to south is

210 miles, and greatest breadth 200 miles; owing to its triangular form, the entire area of this Colony is not more than 26,215 square miles.

The estimated population, according to the returns of 1887, was 142,480, or 5·40 per square mile, and the average death-rate 15·45 per thousand.

The climate is remarkably mild, and is said to possess great restorative powers on constitutions enfeebled by residence in hot countries. The interior is spoken of as being "especially delightful; and here are united, so to speak, the climate of Italy, the beauty of the Apennines, and the fertility of England."

As regards Industrial Products, the most important in the vegetable world is the cultivation of fruit, very large quantities of which are preserved and exported.

Timber is plentiful, and of different kinds, suitable for ship-building, railway sleepers, house-work and furniture; the timbers of Tasmania attract attention in many museums in the Australian Colonies.

The mineral wealth of this Colony consists for the most part of tin and gold. The deposits of the former are very rich, yielding in some cases from 70 to 80 per cent. of pure tin. As yet the minerals of Tasmania have not been worked on a scale of any great magnitude; this is doubtless owing to the fact that the most extensive and valuable of the tin deposits were first discovered comparatively a few years since. Tin in immense quantities has been found at Mount Bischoff, the whole mountain being intersected with veins of that ore. There is good reason to anticipate that this will prove to be one of the richest tin mines in the world.

At Mount Zeehan, in the western part of Tasmania, great discoveries of galena have recently been made. The assays of several tons of this ore have ranged from 60 to 135 oz. of silver to the ton and up to 70 per cent. of lead. An enormous lode of bismuth of extreme richness also exists in the Colony.

At a cost of rather more than £2,250,000, 440 miles of railway had been opened in Tasmania up to the end of 1887, being in the ratio of 1 lineal mile to 59 square miles of territory.

Though last, by no means the least important, is the great Island Continent of

Australia.

Situated between the Indian and the South Pacific Oceans, Australia measures, from east to west, 2,400 miles, or 50 per cent. greater than the width of the Atlantic Ocean between Cape de Verd, on

the West Coast of Africa, and Cape San Roque, on the eastern shore of Brazil; from north to south the distance may be taken at 2,000 miles.

Treating it as a whole, Australia is the largest island on the face of the globe; its area is but little less than 3,000,000 square miles. It is therefore four-fifths of the size of Canada, fifteen times the size of France, and only about one-fifth smaller than the Continent of Europe. It exceeds, by 2,800 square miles, the following countries taken in combination: Russia in Europe, including Poland and Finland, Sweden, Norway, Germany, Austria Hungary, Turkey in Europe, and Greece.

Having regard to the fact that the line of the tropic of Capricorn runs midway across the Australian Continent, it will be obvious that a meridional range of 1,000 miles north and south of this tropical line, 2,000 miles in all, must necessarily give to the country a great variety of climate.

The entire coast-line of this great country is about 8,000 miles in length; it may serve to illustrate the size of Australia if I here mention: 1st, the extent of the two greatest indentations in this coast-line; 2nd, the area of its largest river basin; and 3rd, the length of a reef which runs along the north-eastern coast.

Taking, first, the remarkable embayment known as the "Great Australian Bight," on the south-west coast; its length, from east to west, is about 650 miles (50 miles longer than Great Britain from north to south), and 150 miles broad at the point where the indentation is greatest; its area is 97,500 square miles, or one-tenth larger than Great Britain. The other indent, the Gulf of Carpentaria, on the north-east coast is 380 miles from north to south, and 350 miles from east to west, its total area being 133,000 square miles, or 50 per cent. greater than this country.

Another index of the magnitude of Australia is to be found in the size of the catchment basin of the River Murray and its tributaries, the area of which is 510,000 square miles, or nearly six times greater than Great Britain.

The last of the facts to be adduced, in order to convey a better idea of the size of this country, will be the length of the "Great Barrier Reef," which extends along the north-eastern coast of Australia, opposite Queensland, from below the tropic of Capricorn up to the shores of New Guinea, a total distance of no less than 1,200 miles. This reef, which is a coral formation, from 20 to 80 miles distant from the coast-line, is from 10 to 100 miles wide; it rises from an unknown depth in the ocean

to the level of high-water, thus forming a most remarkable natural breakwater, with a safe and sheltered channel inside.

The motto of this great Continent is: "Advance Australia"; the descriptive particulars now to be adduced will give some idea of her advance in the past, and at the same time afford an index of what may be anticipated for her advance in the future.

I will deal separately with the five several Colonies into which Australia is divided; commencing with the largest of the group, working eastward, and taking them in geographical order.

Western Australia.

This Colony, which was some years ago not inappropriately called "the Cinderella of the Australian family," has recently been described, by the same authority, as about to throw off "her rags and tatters, and emerge a well-dressed princess." It occupies the whole of the western side of the Continent from north to south, and about one-third of its length from west to east, its area being 1,060,000 square miles, no less than two-thirds of which are practically unexplored.

The length of sea-board is fully 3,000 miles. With the exception of the "Darling" range, which runs for about 500 miles parallel to, and within from 10 to 25 miles of, the south-western coast, Western Australia may be regarded as a plain.

The population is exceedingly sparse, the total number of inhabitants, according to the latest returns, being 42,500, or one inhabitant to 25 square miles—the death-rate being 16·83 per 1,000 per annum.

The climate of the southern portion is one of the finest and most agreeable in the world, and this part is very healthy.

The by no means infrequent severe droughts and very heavy floods, experienced in other parts of the Continent, are almost unknown in Western Australia. The annual rainfall at Perth, which is the capital, is on an average 37½ inches.

Most of the European grains, fruits, and vegetables may be cultivated and brought to a high state of excellence in this Colony; the farming of sheep and cattle is largely on the increase, and the Colony is fast taking its place as a producer of wool and live stock; the pearl and pearl-shell fishery is also a flourishing industry.

In the south-west extensive forests produce "Jarrah" timber, one of the *Eucalyptus* tribe, which is of extraordinary durability, and of great value for engineering purposes, especially for harbour

works, as it resists the "teredo navalis" more effectually than any other timber; large quantities in the form of railway sleepers are exported to India, where it has been found proof against the white ants. Towards the extreme south-west, "Karri," another of the *Eucalypti*, occurs abundantly; it is claimed for this timber also that it resists the "teredo navalis"; it sometimes attains a height of 300 feet, and is of great value for piles.

As the country has been explored to a limited extent only, its mineral resources are imperfectly known. Good coal is reported to have been found recently at different parts on the north and west. Lead, copper, and iron exist in abundance, and it is anticipated that gold discoveries recently made will speedily conduce to a great increase in the number of inhabitants, and a consequent necessity for the development of its public works. Hitherto these have been mainly confined to railways, of which 240 miles were opened at the end of 1887, the expenditure thereon to the same date having been about £800,000. In addition to these, a "land-grant" railway, from Albany to Beverley, a distance of 242 miles, was opened in June of this year. The Colony thus possesses about 480 miles of railway, equal to 1 lineal mile for each 2,208 square miles of territory.

Of the million square miles of area less than one-third has been alienated from the Crown and of this third a very large portion has not yet been developed.

South Australia.

The next Colony is known as South Australia; but the name is by no means a happy one, seeing that nearly the whole of its great area lies further to the north than the northern portion of its eastern neighbour, Victoria. Moreover, it stretches completely across the Continent from the Southern Ocean to that portion of the Indian Ocean known as the "Arafura Sea"; its extreme length is about 1,900 miles, and its average breadth 650 miles, being somewhat wider than the length of Great Britain from north to south.

The area of South Australia is 903,700 square miles, or nearly twenty-nine times that of Scotland; its population in 1887 was 317,450, or one inhabitant to 3 square miles, the average death-rate for the year 1886 was 13·38 per 1,000.

The climate has been compared to that of Sicily; but for three months in the year, doubtless owing to its central position on the Continent, it is occasionally subject to hot winds from either side.

The average yearly rainfall at Adelaide is about 21 inches, as deduced from the observations of twenty-seven years.

This Colony is pre-eminently a wheat-growing country, and has been called the Granary of Australia. Various kinds of fruits are profitably grown, and are receiving increasing attention, especially the vine and olive. Wool is also a staple and increasingly valuable article of export.

Large quantities of copper have been raised; and the Burra Burra Mines alone have produced copper to the value of £4,000,000.

Up to the end of the year 1887, there had been constructed 1,420 miles of railway, equivalent to 1 lineal mile to 636 square miles of territory; the cost amounted to £9,162,000.

Great improvements, by dredging, have been effected in the means of communication by shipping between the sea and Port Adelaide, the channel leading up to which has been deepened from 9½ feet in the shoalest part to 21 and 22 feet at low-water. There is a total wharf frontage of about 13,000 feet.

Adelaide is supplied with water from the River Torrens. The works consist mainly of a masonry weir across the river gorge, and two main reservoirs connected therewith by an aqueduct nearly 4 miles in length. The reservoirs, situated between 6 and 7 miles from the city, have together a storage capacity slightly exceeding 1,000,000,000 gallons.

The cost of the scheme, together with that of some minor works for the supply of the suburbs, has been under £1,000,000; the gross revenue has already exceeded the expenditure. Additional works are about to be undertaken at a cost of over £400,000; they will include a storage reservoir of 2,760,000,000 gallons capacity.

Next in order is the Colony of

VICTORIA,

which is bounded on the west by South Australia, on the north and east by New South Wales, and on the south by the Southern Ocean and Bass Strait, its seaboard being about 700 miles.

Separated from New South Wales in the month of July 1851, gold in quantity was discovered in the latter part of the same year, and from that time to the present the progress of this Colony has been extraordinary.

Victoria is the smallest Colony in Australia; its area is 87,900 square miles, or about a thirty-fourth part of the whole. The population is 1,036,119, the ratio being 11·8 per square mile.

As regards climate, there are a few days of great heat in every

summer, but nevertheless there are very many when the weather is pleasant and cool; whilst in the autumn, winter, and spring seasons the greater number of days are characterized by a bright sun, a cloudless sky, and a refreshing breeze.

The average rainfall in the capital city of Melbourne is 25½ inches. The average death-rate, taken over a period of twenty-six years, was 15·71 per 1,000.

The rearing of cattle and sheep—the latter especially—forms one of the staple industries of the Colony, the export of wool being a very large item; but the most valuable of its industries is gold-mining, enormous quantities of this metal having been raised since the year 1851. Other metals also exist, and good coal has recently been discovered. The value of the minerals other than gold raised in Victoria has not hitherto been great; but the gold produce of this Colony since 1851 has exceeded 55,000,000 oz., the estimated value being £220,000,000.

At the end of the year 1887 there were in operation 1,950 miles of railway, giving 1 lineal mile to 45 square miles of territory. Their total cost was £26,500,000.

At Warrnambool, situated on the shores of Lady Bay, a substantial breakwater is being constructed for sheltering the harbour; this pier and its adjuncts form part of a projected work which, when completed, will extend into the bay for a total length of 3,275 feet.

At Port Fairy, until recently known as Belfast, situated at the mouth of the River Moyne, the works executed for the improvement of the entrance consist of two moles, or training piers, running out into the bay for a distance of ½ mile. Substantial training-walls have been erected on the banks of the river, and considerable quantities of reefs of bluestone rock have been removed from its bed by means of dynamite, to such an extent as to render free access for seagoing steamers.

Melbourne, the capital of the Colony of Victoria—"Marvellous Melbourne," as it has well been called—is 40 miles from the seaboard, and situated at the northern end of the great inland sea known as Port Phillip Bay.

Prior to 1835, the ground whereon the City of Melbourne now stands was forest and "bush" in a state of nature, and had never been trodden by the foot of any white man.

In the early part of June of that year—not yet fifty-five years ago—the founder of the Colony of Victoria, John Batman, thus describes his proceedings: "The boat went up the large river (Yarra-Yarra) which comes from the east, and I am glad to state,

about 6 miles up found the river all good water, and very deep." He adds, "*this will be the place for a village;*" and on that very site, there stands to-day "Marvellous Melbourne," a fine and substantially-built city of 400,000 inhabitants. It stretches along the banks of the Yarra, and around the shores of the bay, from Brighton on the east to Williamstown on the west, for a distance of between 16 and 17 miles; the area occupied by the city and its immediate suburbs being 15½ square miles.

As one instance of its wonderful growth and development, it may be mentioned that a corner plot of land at the intersection of two important streets near the centre of the city, originally sold for £45 from a tree-stump as a rostrum, has, with the buildings upon it, just been valued at £493,500.

Until recently the navigation from the head of the bay, by the River Yarra-Yarra up to the city, a distance of 6¾ miles, was through a narrow tortuous channel; this has been greatly improved by the execution of training works in the lower part of the river, and the cutting of a canal near the city across Sandridge Flats. The navigation is now through a channel of one great composite curve about 5½ miles in length, and varying from 6,000 feet to 20,000 feet radius; the saving effected in distance between the bay and the city is thus about 1¼ mile. The new channel will have, in the first instance, a depth of 20 feet and a bottom width of 100 feet.

It is also proposed to execute extensive dock works immediately, at the west end of the city, adjoining the principal railway-station.

The water-supply for Melbourne has been till lately obtained entirely from the Plenty River, 19½ miles from the city. The Yan Yean reservoir is formed by a dam across the valley for a length of more than 3,000 feet; its storage capacity is 6,400,000,000 gallons. The expenditure on the system has exceeded £2,500,000, and further works are in progress to supplement the supply.

An undertaking, which cannot fail to have considerable influence upon the development of the trade and commerce of the Colony of Victoria, is in progress in the province known as Gipps Land. This province comprises nearly 14,000 square miles, equal, in fact, to about one-sixth of the Colony, and nearly twice the size of Wales. By means of the works in progress, Gipps Land, through its chain of lakes and rivers, will be brought into direct communication by sea with the outer world. The works consist of the formation of a new channel through the sand dunes between the lakes and the ocean, at the seaward termination of which two piers are in course of formation. Although the works

are by no means complete, a low-water depth of from 10 to 12 feet has been secured.

The existence of coal in Gipps Land has been known for some time. Within the last month some very rich seams have been discovered near the surface; after being tested in railway locomotives, this coal is said to be in every respect equal to the best hitherto found in Australia.

Irrigation on a large scale has been fostered by the Government of Victoria. In the Mildura district alone, the proprietors of the Irrigation Settlement have expended £120,000 in the development of their property. The area at present intended to be irrigated in this Colony amounts to nearly 1,200,000 acres; cash advances of the Government thereto have been nearly £1,000,000.

New South Wales.

The first settlement in Australia, New South Wales, was founded in 1788; the centenary of its foundation was celebrated last year.

Originally the whole of the eastern side of the Continent belonged to this Colony, when its area was considerably more than 1,000,000 square miles; but, in consequence of the three great severances which have been made, viz., South Australia on the west in 1836, Victoria on the south in 1851, and Queensland on the north in 1859, the area has been reduced to 311,000 square miles, which is about the size of Great Britain and France united.

A range of lofty hills runs parallel to the sea-coast, at an average distance of about 30 miles from it. The country on the eastern side of this range is a rich undulating plain, intersected by numerous rivers. On the western side the country consists of table-lands, developing into vast plains. Several important rivers flow into the Pacific Ocean on the eastern seaboard.

The population is 1,043,000, or 3·4 per square mile.

Nearly every variety of climate is found, and the Colony is, on the whole, very salubrious. The climate of the capital, Sydney —where the thermometer is very rarely below 40° Fahrenheit— has been compared with that of Naples, which is stated to be 5° hotter in summer, and 5° cooler in winter, than Port Jackson, on the shore of which Sydney is situated.

The average rainfall at Sydney is 49½ inches; the average death-rate was 15·52 in 1,000 for the year 1887.

The great staple produce of New South Wales is wool, enormous flocks of sheep having been kept until recently for its production

alone; however, a large trade in the export of frozen meat has come into existence. Sugar, maize, tobacco, are grown and exported in large quantities; the Colony is also favoured with magnificent forests containing many descriptions of valuable woods.

Gold, silver, tin, copper, iron and other metals are found in abundance in various parts of the Colony, as well as diamonds and other precious stones. The Broken Hill Proprietary Silver Company has been recently turning out from 80 tons to 100 tons of silver lead, and about 10,000 to 14,000 oz. of silver per week; for the six months ended with October 1888 this mine paid a dividend of £2 monthly upon each share (£19 paid up), and the Directors contemplate the time when these dividends will be doubled. The manager reports that there are more than 700,000 tons of ore in sight, averaging 31 oz. of silver to the ton.

Nearly 3,000,000 tons of coal were raised during the year 1887. The coal-measures of New South Wales are known to exist under an area of 24,000 square miles, equal to about one-half the area of England, or about five times that of the coal-measures of Great Britain.

There had been constructed at a cost of £26,554,000, up to the end of 1887, 2,040 miles of railway, equivalent to 1 lineal mile to 152 square miles of territory.

In connection with railways mention must be made of the great bridge over the Hawkesbury River, forming the last link in the continuous railway system between the principal cities of the four Colonies of South Australia, Victoria, New South Wales and Queensland. The length of the bridge between the abutments is 2,900 feet. Its most remarkable feature is the depth to which the foundations of the several piers, six in number, were carried; they were sunk in caissons to depths varying from 101 feet below high-water level to 162 feet; it is claimed for the last named that it is the deepest bridge-foundation in the world.

The most remarkable engineering works in connection with railways in New South Wales are those which have been constructed for the passage of the Western Railway over the Blue Mountains; these are passed by a series of zigzags on each side of the range, on gradients, of which the steepest is 1 in 30. The line ascends from a height of 87 feet above sea-level at the base to an elevation of 3,758 feet at the summit, the distance between the two points being 50 miles. So rugged was the face of the hill at some points that those engaged upon the survey had to be lowered down the cliffs with ropes to enable them to measure and peg out the line.

The beautiful harbour of Sydney, known as Port Jackson, is

broken up in all directions into capacious open-mouthed bays, by the numerous promontories jutting into it; these bays are harbours in themselves. The sea frontage of Sydney is skirted with stores, warehouses and wharves. Vessels drawing 27 feet can enter the harbour at low-water, and in many parts of the city lie close inshore; the wharves have of late been greatly improved and extended.

The most important engineering work of recent construction in the harbour of Sydney is the graving-dock on Cockatoo Island, more than 600 feet long, with an entrance 84 feet wide, and a depth of water over the sill at spring-tides of 30½ feet.

On the south head, at the entrance to Port Jackson from the Pacific Ocean, one of the most powerful electric lights in the world is exhibited from the Macquarie Lighthouse; it is about 350 feet above sea-level, and is visible at a distance of about 30 miles.

For the supply of Sydney and its suburbs new water-works have lately been completed; the sources of supply are the Nepean, Cordeaux and Cataract Rivers. Part of the Nepean water, being deflected by a dam, runs through a tunnel 4½ miles long into the Cataract River, where it is again dammed back. Thence, by a series of tunnels, canals, flumes and pipes, it is conveyed a distance of 36 miles to the main storage-reservoir at Prospect. The carrying capacity of the works to this point is 150,000,000 gallons daily. The dam of the Prospect reservoir is 7,260 feet long, and its greatest height about 85 feet. From this point there is a further distance of nearly 21 miles over which the water is conveyed in steel, wrought-iron or cast-iron pipes, varying from 6 feet to 42 inches in diameter, to the service-reservoir for the supply of Sydney proper.

Sewerage works for various suburbs of Sydney have recently been authorized by the Colonial Parliament at an estimated cost of £960,000. Outfall sewers for the city and a portion of the suburbs have already been completed at an outlay of about £700,000. The complete scheme for the city and the surrounding district is estimated to cost nearly £3,000,000.

Great improvements have been effected at the port of Newcastle, at the mouth of the Hunter River, the great coal-shipping port of the Colony. The southern breakwater has proved of great service in sheltering the entrance, where formerly vessels had very heavy seas to contend with during south-easterly gales; the depth of water at the quays is about 22 feet, and from 27 feet to 30 feet in mid-harbour. Extensive works are in progress for the improvement of the entrances to the Clarence and Richmond Rivers.

QUEENSLAND,

the last born of the Australian family, was separated from New South Wales only thirty years ago, viz., on the 10th of December, 1859.

It is bounded on the south by New South Wales, on the west, for the southern half of its length, by South Australia, whilst its northern half is bounded on the west by the eastern shore of the Gulf of Carpentaria. The Colony tails off to a point at the extreme north, known as Cape York, on the south side of Torres Strait. The eastern shores of Queensland abut on the Pacific Ocean, three-fourths of its length, the portion north of the tropic of Capricorn, being washed by the waters of the Coral Sea.

Queensland is 1,300 miles in length from north to south, its average breadth is 800 miles, and its area 668,500 square miles, being more than double that of the Colony of New South Wales, of which it originally formed part; it is nearly four times the size of France, and twelve times that of England and Wales. The length of seaboard is 2,550 miles, the longest on this Continent, with the exception of that of Western Australia.

The white population in 1887 was 366,940, or at the rate of one inhabitant for every 2 square miles; the death-rate over an average of the years 1886 and 1887 was 15·6 per thousand; the rainfall at Brisbane on an average of twenty-seven years has been 49 inches.

The growing of sugar, arrow-root, rice, coffee, wheat, timber, for decorative and building purposes, the rearing of cattle and sheep, and the export of frozen meat, hides, and wool, all form important items of industry and commerce.

The mineral wealth consists of gold, tin, and silver, and other metals have been largely exported. Within the last fortnight an announcement has been made that on one of the islands in Torres Strait gold has been found, with every prospect of the field turning out a prosperous one.

A silver lode has been recently discovered near the Gulf of Carpentaria, the assay of ore from which has been declared to be at the rate of "800 oz. to the ton, and the lode traceable for 30 miles." The Mount Morgan Mine, near Rockhampton, is certainly one of the richest in the world; this mine is turning out gold to the value of £128,000 per month; of this about £28,000 go in working expenses, and the balance, £100,000, in dividends to the shareholders. The value of the Mount Morgan Mine has been estimated at from £9,000,000 to £17,000,000 sterling. A shaft has been sunk down the centre of the Mount 300 feet deep, and the ground tested

by tunnels at intervals. It is stated that an area of 9 acres round this shaft is as rich in gold as the quarry, for it is in fact a quarry which is being worked at the top.[1]

The returns up to the end of 1887 show that by an expenditure of £12,220,000 a length of 1,770 miles of railway had been opened, being in the proportion of 1 lineal mile of railway to 378 square miles of territory.

Considerable improvements have been recently effected by dredging through the bar, and in the channel of the river leading up to Brisbane, so that large vessels, including ocean mail steamers, can reach the city.

A scheme for the supply of water to the city of Brisbane has just been adopted; the estimated cost is about £500,000.

At the Fitz-Roy River, dredging operations have been carried on and training-walls constructed, from the sea up to the town of Rockhampton, so that vessels of 1,500 tons can now come up to the wharf.

At the entrance of the Pioneer River, leading up to the town of Mackay, near to which there are numerous sugar plantations, extensive training-banks have been commenced, having a total length of 6 miles, and by means of dredging operations it is intended to establish a continuous deep-water channel of 4½ miles between the sea and the town.

At the port of Townsville, eastern and western breakwaters are in course of construction, and somewhat extensive dredging operations are contemplated. This is the port for the rich gold fields of Charters Towers.

At the entrance to Norman River, in the Gulf of Carpentaria, it is proposed to form a deep-water channel, about 3 miles in length, and across the bar in continuation of the existing river channel, having a low-water depth of 12 feet, thus opening up the navigation to the town of Normanton, the present outlet for the Cloncurry gold and copper mines. The new channel is expected to be completed in the course of next year.

The questions may here not unnaturally arise: Have the Colonies been justified in constructing these public works? and, Are they capable of bearing the financial obligations they have thereby imposed upon themselves?

[1] Th[illegible]lly sold at the rate of 5s. per acre.

Circumstances warrant a reply in the affirmative, for it does not appear to be too much to say that, taken as a whole, the market value of the public works already executed by the Colonies would be fully equal to their cost.

The early settlers in our larger Colonies, finding the lands of their respective homes in a state of nature, have, in many cases, been brought face-to-face with large and pressing demands, for the execution of such Public Works as have been absolutely essential for securing ready and economical intercommunication between district and district, and more especially between the sea-board and the interior, involving roads, railways, &c., within their own borders, and also between themselves and the outer world in general, and the Mother Country in particular; in the latter case there has arisen, of necessity, the creation of ports and harbours, effected, for the most part, by the improvement of natural facilities in the shape of bays, estuaries, or tidal rivers.

Further, in not a few instances, our Colonies have found it absolutely necessary to incur a by no means inconsiderable annual expenditure, in the way of subsidies to ocean-going steam-ships of the largest class and greatest speed, in order to insure frequent, regular, and rapid communication with the rest of the world, but chiefly with "the Old Country."

The question, whether our Colonies are capable of bearing their financial burdens can only be answered in general terms; but perhaps the most conclusive reply in the affirmative is to be found in the readiness with which invitations by British Colonies for large loans are generally met by far-seeing individuals in the Money Market within the City of London.

Without dwelling at length on this topic, let me remark that there are important factors which cannot fail to have exercised a material influence on some at least of these individuals.

It is doubtless not overlooked that in our larger Colonies vast areas of lands belonging to their respective governments are yet unappropriated, and these may be regarded as so much capital in reserve. Moreover, in the case of some of the government lands occupied by "squatters," the rentals are subject to a percentage of increase periodically.

Further, the financial position, and consequently the spending power of the Colonies, is, of course, favourably affected by the present low rate of interest obtainable for capital in this country. Many British Colonies are now able to raise loans at about 3½ per cent., these rates sometimes carrying a premium; whereas the same Colonies not so very long ago found it necessary to offer 6 per cent.

in order to procure the money necessary to enable them to keep pace with their requirements.

When dealing separately with the several Colonies, the proportionate area of territory to each mile of railway has been stated; but this ratio is such an important gauge of their respective capabilities for future developments, that the facts as regards the larger of the Colonies mentioned may with advantage be again quoted for comparison with Great Britain and with each other.

Name.	Area in Square Miles.	Lineal Miles of Railways.	Square Miles of Territory for each Lineal Mile of Railway.
Great Britain	88,000	20,000	4·4
Victoria	87,900	1,950	45
Tasmania	26,215	440	59
New Zealand	104,000	1,750	59
Natal	18,750	220	86
Cape Colony	213,900	1,700	126
Ceylon	24,700	180	137
New South Wales	311,000	2,040	152
Canada	3,610,000	12,500	290
Queensland	668,500	1,770	378
South Australia	903,700	1,420	636
Western Australia	1,060,000	480	2,208

It is noteworthy that whilst our own country has for the last three hundred years been steadily building up a great empire, by the acquisition of colonial possessions in various parts of the globe, it is only within the last decade that any other European State has taken any action of importance in the matter of colonization. It is also worthy of remark that, within those portions of the world possessing such a climate as to admit of the employment of white labour upon out-door operations, there is not now a single region of any magnitude available for colonization. It is an indisputable fact that no inconsiderable part of the area of the globe is under the imperial ægis of Britain; can this be held to be accidental in the ordinary sense of the word? I trow not. For myself, I can only see in it the working of an overruling Providence.

Permit me, before concluding, to say a word as regards the capabilities and possibilities yet to be developed by the Civil Engineer—whether in the Colonies or in the Mother Country. The field is indeed a vast one; great advances have been recently made, and are still being made, in every branch of engineering, among which the foremost place must, at present, and most

appropriately, be assigned to that great structure, the Forth Bridge; of the principles and of many of the details involved in which we may, it is to be hoped, confidently look forward to a technical description being presented to our Institution by the Engineers of the work.

Notwithstanding these great advances, he would be rash indeed who would venture to prescribe a limit to engineering achievements. I do not pretend to dogmatize, but venture to express my conviction that so long as the present dispensation may last, so long will there be a continuous progress in the science and practice of every branch of labour in the field appertaining to the Civil Engineer. Neither to the Engineer, nor indeed to any other disciple of natural science, would it seem to have been announced —I say it with all reverence—"Thus far shalt thou go, but no farther."

I have submitted in detail the sizes of the most important of our Colonial Dependencies; it is only, however, by summing up their areas that anything like a correct idea of the magnitude of the British Empire can be arrived at.

Consider the British Colonies in groups, corresponding with the several quarters of the world:—

	Square Miles.
In Europe (round numbers)	120
" Asia, including India	1,700,000
" Africa	770,000
" North and South America, including the West Indies and other islands	3,650,000
" Australasia, including New Guinea and other islands	3,200,000
Making a Grand Total of	9,420,120

As a matter of fact, our Colonies proper, exclusive of British India, are equal in extent to one-sixth, or, including India, to nearly one-fifth of the entire land area of the globe.

Bearing in mind how small—indeed how comparatively insignificant in point of size is this little island of ours, "this precious stone set in a silver sea," now become a Mother of nations, we cannot fail to realize that, as members of this mighty Empire we are partakers in a great and goodly heritage.

That the benefits of civilization have gone forth with our fellow-countrymen to the most distant parts of the earth cannot for a moment be doubted; nor will it, I trust, be questioned by any whom I address, that the greatest of all has been the

Gospel of the Grace of God. Granting this, it may with confidence be affirmed that, among the *material* benefits which surround our fellow-countrymen (our "kith and kin") in their new homes across the sea, by no means the least will be those which can fairly be claimed as having been attained through the instrumentality, the skill, and the labours of the British Civil Engineer.

On the motion of Sir John Fowler, K.C.M.G., Past President, seconded by Sir Charles Hutton Gregory, K.C.M.G., Past President, it was resolved by acclamation :—

"That a cordial vote of thanks be passed to the President for his interesting address, and that he be asked to permit it to appear in the Minutes of Proceedings."

The President, after acknowledging the resolution and consenting to the publication of his address, proceeded to distribute the Medals, Premiums, Miller Scholarship, and Miller Prizes awarded by the Council for the Session 1888–89 (vol. xcviii. pp. 224 and 225).

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19 November, 1889.

Sir JOHN COODE, K.C.M.G., President,
in the Chair.

(*Paper No. 2404.*)

"Water-Tube Steam-Boilers for Marine Engines."

By JOHN ISAAC THORNYCROFT, M. Inst. C.E.

WATER-TUBE boilers are those in which the water to be evaporated is contained within the tubes which form the heating-surface.

In the year 1878, Mr. Flannery contributed a Paper to the Institution,[1] showing what progress had been made up to that date with this kind of boiler at sea. This communication and the discussion which followed clearly proved that, although considerable saving of fuel might be obtained with water-tube boilers, as then made they were unsuitable, because the tubes forming the heating-surface were burnt, owing to insufficient circulation.

The subject to which the Author desires to direct particular attention is therefore circulation; and by this term to convey the idea of motion of the water contained in a steam-generator from the upper surface of the liquid, down to the lower parts of the generator, and returning again to the upper surface.

Motion of water, simply from the point where the feed-water is admitted to a point in the boiler where it becomes steam, he would wish to hold distinct from the idea of circulation. Having so defined the term, he would divide all boilers into classes depending on the manner in which circulation takes place. The motion may depend on difference of density in the ascending and in the descending columns of water, or mechanical means may be provided to induce or compel the necessary motion of the water in the generator.

In order to give more definite meaning to the classification of boilers by these peculiarities of circulation, the Author would direct attention to Plate 1, Figs. 1 to 8.

If an open vessel containing water, such as shown in Plate 1,

[1] Minutes of Proceedings Inst. C.E., vol. liv. p. 123.

Fig. 1, should have its lower surface uniformly heated, circulation will immediately commence. Before the water begins to boil this circulation will be feeble, owing to the small difference of density in its different parts. When, however, boiling takes place, the action will become energetic, but will be wanting in order; it is struggling and confused, and nowhere acquires any high velocity.

This may be taken as a model of probably the oldest and simplest form of boiler, and the circulation has the same character as that of by far the greatest number made, including modern marine boilers, and, as Mr. Flannery showed, the first water-tube marine boilers also.

Plate 1, Fig. 2, represents Mr. Loftus Perkins' water-tube boiler. This belongs to the class in which there is no circulation, and consequently pure water must be used to avoid the deposit of sediment at and about the water surface, or that part furthest from where the feed-water enters.

Plate 1, Figs. 3 and 3*a*, represent a large class, in which straight tubes are placed over the fire, and, by being divided into numerous sections, avoid the difficulties to some extent caused by unequal expansion; but the circulation is not sufficient to allow the boilers to be forced to the degree necessary to make a light steam-generator, although it is assisted by a pump returning water from a separate vessel used to divide the water from the steam. In this particular it is similar to Plate 1, Fig. 4, Mr. Herreshoff's boiler, which, however, seems to gain by having only one passage, so that any water in going through the boiler must traverse the entire heating-surface. This boiler has been made to stand forcing much better than the Belleville. The circulation, when the rate of working is changed, is difficult to manage. In proper working water comes over with the steam; with a reduction in the flow of steam this is liable to cease; superheating then commences, and if more feed-water be suddenly pumped in, the effect is at first to suspend boiling in some of the coils, with the result of reducing the volume of the water contained, and thus failing to arrest the superheating as quickly as might be wished.

The Field tube, Plate 1, Fig. 5, is the first example given of circulation depending on difference of density, in which circulation is for the most part systematic. The Field tube consists mainly of two concentric cylinders; the outer surface of the larger one is heated, the intermediate space between them forms a channel for the ascending current, and the denser water descends

within the inner tube protected from heat. Boilers having tubes on this plan, even with tubes of small diameter, stand hard firing, although the flow of water within them must be greatly retarded by dividing the internal space and increasing the frictional surface.

Plate 1, Fig. 6, represents the boiler of Mr. du Temple, in which the circulation is similar to that of the Field tube. It has an external tube, not affected by the heated gases, for the downward flow of circulating water. The tubes forming the heating-surface terminate below the normal water-surface, so that there still remains a region in which confused circulation takes place. The final separation of the steam from the water is delayed by the projection of masses of water into the steam-space.

The Field tube and Mr. du Temple's boiler, however, are much to be preferred to any in which mechanical means are required to assist the circulation, for they solve the problem of a boiler with sufficient force in the different densities of the water contained in it to promote circulation in small tubes.

In Plate 1, Fig. 7, is represented the first example in which the circulation is systematic throughout. This is the boiler of Mr. Matheson, and was introduced to the Author as one which had been constructed for distilling water for chemical purposes, where purity was of great importance. This boiler consists of several coils of copper tube encircling a furnace, and afterwards delivering into the top of a vessel which forms a separator, and from the bottom of which the coils first start. When the separation of the steam and water takes place above the water-level, it can be accomplished in the smallest possible space, for there is no remixing. The most favourable condition for separation is when the mixed steam and water is made to take a curved path, the heavier portion selecting the greater radius and flowing gently upon the mass of water already separated. The small space in which separation can be effectively carried on when this principle is employed is illustrated by Plate 1, Fig. 8, which represents a boiler made by the Author's firm for a shallow steamer to navigate the rivers in Central Africa. The volume of the steam-space in this separator is only 2·65 times that of the cylinders supplied with steam, the more common ratio being about 90. A better idea is given by stating that the steam-room is only equal to a supply of one-quarter of a second, while the smallest space found sufficient in a locomotive boiler represents steam for about six seconds.

Many forms of separator have been devised to dry steam taken from boilers in a wet state. This is, however, an acknowledgment

of imperfect boilers, and represents work which should have been done before the steam left the generators. The quantity of water contained in a steam-boiler cannot be reduced conveniently below certain limits, without making the boilers difficult to manage when the engines are suddenly stopped.

There is, however, one feature in a boiler in which the water is thoroughly circulated, in that it allows the volume of water to be considerably reduced without increasing this source of trouble. Where rapid circulation throughout takes place, in order to materially increase the steam pressure, the whole of the water in the boiler must be heated to a temperature to which the higher pressure is due. In the common boiler with a large heating-surface near the water-surface, steam may accumulate in the steam-room, while only the surface-water is heated to the temperature to which the steam is due.

Circulation is governed by several conditions, and amongst these the pressure in the steam-generator is an important one.

In water-tube boilers high-pressure is favourable to good working, but it is not sufficient to consider this alone. When very high pressure is used, long tubes of small diameter may succeed; but pressure practically does not affect the density of the descending column, while it greatly increases that of the ascending one, thus lessening the difference by which the circulation is maintained.

The difference of density may be considered as a propelling force available for causing circulation, and the channel should be so proportioned as to give the highest velocity practicable, without danger of overtaxing this propelling force. In this way, accumulation of scale on the heating-surface may be greatly retarded.

The diameter of the tubes should increase with their length; but when their upper ends are above the normal water-line, like those in the "Propontis," Plate 1, Fig. 2*a*, described by Mr. Flannery, there is certainly danger in making them too large. In this case, instead of the steam and water passing over in foam, the steam alone will leave the tubes. The impurities brought in with the feed-water will gradually accumulate in the upper part of the tubes, and will lead to their destruction.

The Author attributes the failure of the up... 2½-inch tubes in the "Propontis" to thi... that obstruction from deposit... the more serious failure... date.

In selecting the most suitable diameter for tubes, safety to the stokers demands that the failure of one tube should not be sufficient to cause a rush of gases from the fire-door. The Author thinks this will restrict the diameter of the tubes to something less than 1½ inch. This will impose a limit to the length, because the amount of steam generated in a tube of given diameter is proportional to the length, and, while the available head for causing discharge only increases in the same ratio, the resistance to discharge may be taken as increasing as the square of the velocity multiplied by the increased length. True, this resistance becomes less as the amount of water discharged diminishes, and the head increases, but the safe duty is passed when the head available is only sufficient to discharge steam alone.

Greater length in proportion to diameter is admissible with less intensity of heat, and where special lightness is required the tubes should be as small as practicable, because in this way the weight of water and material and the space occupied will be a minimum.

The Author made experiments in 1882 with copper tubes in a smith's fire, to ascertain the effect of intense heat on tubes of small diameter. He found that water could not be driven from a ½-inch tube 6 feet long, when a length of 3 feet was exposed to a fire prepared as for welding. In this case the pressure in the tube, where it was exposed to the fire, only slightly exceeded that due to the atmosphere, and the head available for circulation was less than 2 feet. With tubes of less diameter, tried under the same conditions, the water was driven out and the tubes soon became overheated and fused in the fire.

A small experimental boiler was afterwards made in which seven tubes, 1 inch in diameter, were exposed to severe heat in a fire-brick flue. The fire was unable to damage them, although the mean evaporation per square foot of [illegible] was equal to about 18½ lbs. of water per hour, from and

The movement of water with[illegible] ifficult t[illegible]:
but in the tubes experim[illegible] ic pressu[illegible]
from the upper end a[illegible] a perio[illegible]
A rush of combin[illegible] always
period during [illegible] spended
When t[illegible] tube t[illegible]
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[illegible] ke pl[illegible] nce
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panded to extend up to a level with the point of discharge, while only balancing in weight the shorter descending column. In this way, instead of circulation commencing with the first application of heat, it is prevented until sufficient propelling force has been acquired to overcome the resistance above referred to. When, however, the diameter of the tubes is sufficiently small, no danger would appear likely to arise from this condition, for a very slow rate of boiling within the tube would soon lessen the density sufficiently to destroy the conditions of equilibrium between the ascending and the descending columns. It will thus be seen, that if there is a period in which the flow from the upper end of the tube is suspended, while steam is accumulating within the mass of contained water, the expansion of this steam, at the same time that it pushes forward the upper end of the column, will also cause motion in the opposite direction in the lower end. In this way the column will be expanded so as to reach the point of discharge, and it will also be reduced in weight by the amount of water which has been driven from the bottom of the tube.

At this point in the periodic action, if it be granted that the rate at which heat is absorbed during the cycle of operations is regular, at the same time that the column loses weight there will be a corresponding diminution in the pressure, and consequent lowering of the boiling point; from this cause the rush from the upper end of the tube will be increased, while the formation of vapour will tend to keep back the water at the lower end.

The result of what has now been described to have taken place in the tube brings it to a condition in which the ascending column has been greatly reduced in weight, and the resistance to discharge at the upper end also reduced by the attenuated nature of its contents. Accordingly there is a rapid flow of water, unmixed with steam, into the lower end of the tube, bringing its condition to that in which discharge from the upper end of the tube will be suspended, and the cycle of its periodic discharge is complete.

If a tube is considered in which the upper end is drowned or normally covered with water, important differences arise. At first sight it would appear that the conditions are more favourable to the kind of generating tube under discussion than those last described, for there is no initial obstacle for the circulation to overcome. In this case, it has been pointed out by Professor Osborne Reynolds that circulation increases, until the density of the ascending column has been reduced to about one-half that of

the descending one, after which point the amount of water in circulation diminishes.

If from any cause the flow becomes unstable, and the tube to a great extent emptied of water, the inertia of the column of water entering from below, by retarding the refilling of the tube, will afford an opportunity for the water at the upper end to re-enter the drowned tube, and thus resist circulation by loading the tube with a mass of compact water in the upper part. Steam may thus be imprisoned for a short time in a portion of the tube, and cause overheating. Of course, this would not be a condition of equilibrium in a boiler in which the descending column consisted of water alone, unless the velocity in the descending column were sufficiently great to represent a loss of head, equal to the loss of head caused by the imprisoned steam in the circulating tube. It is, however, a strong argument in favour of protecting the descending column from all heat in boilers where drowned tubes are used.

Plate 2, Figs. 9, 10, and 11 are intended to illustrate what takes place, so far as the Author can imagine, in a generating tube. In Fig. 9 different points along the base-line may be taken as different rates of evaporation within a tube, the extreme left of the base being a point where no heat is transmitted to the water, and where consequently there is no evaporation. Equal spaces to the right represent equal additions to the heat transmitted, and, as the pressure in the diagram is supposed to be constant, the inclined straight line, forming an angle with the base, cuts off the vertical ordinates at points representing the rates of evaporation for the different rates of heat transmitted. The upper continuous curved line cuts the vertical ordinates at points representing the total flow through the tube, and the portions of these ordinates between the curved line and the inclined straight line before-mentioned represent water. In this way it is seen, starting from the origin, that while the volume of steam increases regularly, the volume of water, at first increasing rapidly, soon ceases to do so, and then gradually diminishes. The line representing the total flow tends to follow the steam-line and ultimately meets it.

On the same diagram is another curved line dotted; this line represents head or propelling power for circulation, and it will be seen that the greatest circulation of water takes place when the density of the mixed steam and water in the tube is about one-half that of water. As higher rates of evaporation are attained the steam gradually monopolizes the channel. This diagram clearly

demonstrates the results of different rates of evaporation at constant pressure.

Fig. 10 (Plate 2) illustrates what takes place when both heat and pressure are so varied that the volume of steam produced is constant, the base of the diagram representing the increase of pressure from 0 to 20 atmospheres. The rate of evaporation has been so chosen that the volume of steam and water is approximately equal throughout the diagram. As pressure becomes greater the density of the steam increases, and this increased weight, becoming a considerable element of resistance, diminishes the total volume of flow. This diagram is of interest in giving an idea of the work that can be got out of a tube of certain dimensions at different pressures; the dotted line cuts off vertical ordinates at points representing the total heat in foot-lbs. of energy communicated to the water in the pipe at the various pressures.

In Plate 2, Fig. 11, heat is made constant and the pressure variable. The diagram takes nearly the same form as Fig. 9, the reduction of pressure having very nearly the same effect on circulation as increase of heat. The Author has endeavoured to estimate the conditions of working in the boiler to be afterwards described, and has shown approximately by Figs. 9 and 9*a* the limits between which the tubes are worked. The relative amount of steam and of water in circulation, in what may be taken as the average of the tubes, is clearly indicated.

There is one rough test by means of which an entirely independent estimate may be made. This test depends on the fact, that when no steam is being drawn from the boiler, and it is simply acquiring greater density in the steam-space, while the water is increasing in temperature, the amount of steam in circulation in the tubes will be greatly reduced, and the fall of the water-level in the separator will give a measure of the change. This fall, however, is less than the fall in a locomotive boiler under similar conditions, being only about 2 inches for a boiler in which the total depth of water is 4 feet 10 inches; but the fact must not be neglected, that the section of water in which the change of density takes place is five times less than the area of the water-surface in the separator where the change of level is observed.

The next important point to be considered is weight, and it is clearly demonstrated that in a tubulous boiler, where the circulation can be made systematic throughout, steam can be more rapidly brought from the lower parts of the boiler and delivered into the

steam-space than in a boiler of the ordinary form, because the increase of bulk of what is called the water in a boiler, that is the water and steam below water-mark, depends directly on the amount of time the steam is submerged.

By the use of a water-tube boiler it is possible to considerably reduce the amount of water.

In the one which will afterwards be noticed, the weight of water is only about two-thirds of that required for an equal locomotive boiler. This reduction of volume of water corresponds to a saving of material necessary to contain it; and, while considering the space enclosed within the pressure-resisting walls of the boiler, the Author would direct attention to a very important difference between water-tube boilers where the steam and water only have a pressure-resisting envelope, and those of the ordinary form which have a strong shell containing not only the steam and water, but likewise the fire and products of combustion. These latter are again enveloped in a second or inner shell, and thus are covered twice by material to resist the whole pressure contained in the boiler. This is one evident cause of the great saving of material possible with the water-tube system.

In the discussion which followed a Paper submitted by the Author to the Institution in 1881, Sir Frederick Bramwell drew particular attention to the fact,[1] that in ordinary boilers much material was spent on surface that was inoperative for forming steam, and the water contained in them was large in amount. Sir Frederick Bramwell considered that the boiler offered the best opportunity for reduction in weight in propelling-machinery, an opinion which appears to have been well founded. No sensible gain has been made in the lightness of engines since that time, but the Author's firm, by changing the form of boilers from locomotive to water-tube, has been enabled to reduce their weight by about one-third. This reduction in weight has been accompanied by greatly superior steaming-power, economy of fuel and less forcing of the fires. Last but not least, the safety of the boats and of the crew has been materially increased.

In considering the question of weight in water-tube boilers, the necessary firebrick casing has been an important element. Mr. Loftus Perkins found a substitute in a double iron casing enclosing a layer of finely divided carbon. This formed an excellent non-conductor, but required an air-tight case. The case had, however, to resist a considerable degree of heat, as it

[1] Minutes of Proceedings Inst. C.E., vol. lxvi. p. 136.

formed a flue in which the heating-tubes were all contained, the water-tubes themselves not constituting the external case of the boiler. The firebrick used in the boiler designed by the Author is all in the firebox, and although adding to the weight is to some extent useful by keeping the gases hot during combustion; but firebrick does not serve this purpose when placed in the flues, and coming in contact with the gases after they have been cooled by the heating-surface. The Author thinks it right to acknowledge that Mr. du Temple has advanced the subject of water-tube boilers for marine purposes, by designing a boiler in which sufficient circulation is maintained to permit the use of small tubes of considerable length; and this would appear to be a very light boiler if the weight of the firebrick chamber in which the tubes are placed could be neglected.

The conditions favourable to combustion demand attention. When it is no longer necessary to enclose the fire in a space which has been secured at the price of material to enclose it, capable of resisting the boiler-pressure, much more space can be allowed in the firebox. The gases will then have time to combine before being hurried across the heating-surface. When absorption of the heat is considered, care must be taken to cause the heated gases to pass uniformly as far as possible over the whole heating-surface; for, when the opening leading to the chimney is situated at the upper part of the boiler, the gases will tend to take a direct line to it and render much of the surface of little value. Provision must therefore be made to prevent this. On shipboard it is not convenient to bring the chimney down to the base of a boiler, and cause the gases from an ample flue-area to select themselves by their density, and thus retain the heated gases as long as possible. In ascending flues, the area must be so limited that the velocity in the flues causing sensible resistance shall prevent unequal escape of the hotter gases. It is also desirable that the gases within the flues should cross and recross the tubes and not move simply along them.

In studying economical production of steam the effect of forced draught must not be neglected. When a large heating-surface for the work to be done is given to a boiler with chimney draught, the combustion is necessarily carried on in currents moving in a sluggish manner, and under these conditions it has been long known that more air per lb. of fuel is required than when combustion takes place under a forced draught. There does not seem any evident reason for this fact, but the Author thinks there may be some analogy in the beautiful experiment in which Professor

Osborne Reynolds introduced a coloured stream of liquid into a cylinder of flowing water, and showed that the two streams might continue to flow together indefinitely without mixing until a certain critical speed was reached, after which new forms of motion were produced in the current, and mixture rapidly became complete. In the evaporative experiments made with the boiler hereafter described, the fires were at first worked with chimney draught only, and afterwards air-pressure was used varying in amount, the greatest of which was equal to a column of 2 inches of water. This statement, however, is liable to be a little misleading, for the rapid motion of the air across the top of the vessel's funnel constitutes a source of draught which is not properly chimney draught, or that depending on the difference of density within and without the chimney.

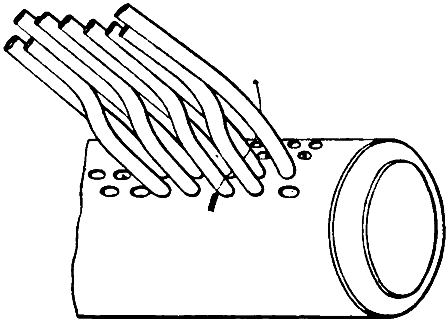
In the boiler experimented on, although there is a considerable permanent opening in the fire-door, it was found that a very thin fire was necessary to ensure complete combustion under natural draught. Many designs have been proposed for utilizing the forced draught produced by a fan. The Author believes that a fan to force air into the stoke-hold is the simplest and best; and if care is taken to distribute the air in such a manner that it has not a high velocity on entering the stoke-hold, no inconvenience from it will be felt; on the contrary, the place will be rendered more cool and comfortable. This method of using a fan was first employed by the Author's firm in a screw-yacht "The Gitana" in 1876, and has since spread to all the navies of the world, and seems likely to be used also in the merchant service. The Author would claim the credit of having first employed this method of forced draught for his father, who in 1855 made a small steamer, or perhaps more properly a model. It was fitted beneath the deck with a fan which delivered air around its circumference into the hold of the vessel. By enclosing the machinery so that the only passage for the escape of the air was through the fire to the funnel, the fire was forced with perfect success.

Fig. 1, p. 52, and Plate 2, Figs. 12, 13 and 14, represent a boiler designed by the Author embodying the principles of circulation and combustion which appear to him most suitable for marine purposes. Lightness of structure and strength to resist internal pressure have been particularly kept in view, and the evil effects of unequal expansion have been provided for by the curved form of the tubes, which afford practically the whole heating-surface.

These tubes are shaped so as to make an arch over the fire, only

allowing escape for the products of combustion by a series of narrow openings a little above the surface of the fire. In the upper portion of the arch, each tube by touching its neighbour forms a practically continuous roof, and encloses a large space above the fire-bars

Fig. 1.



extending the whole length of the boiler. The tubes which compose the firebox, having arrived at a point near the centre of the arch, alter their direction of curvature, and, after meeting, turn apart again to give room for the largest vessel in the boiler. By keeping in contiguous lines, they afford a protection from heat to this vessel. In a similar way in which the firebox is formed, two rows of tubes unite to make the external casing of the boiler, thus constituting a flue in which numerous other tubes are placed. The ends of all these tubes are secured in three horizontal cylinders, of which two serve the purpose of supplying water to the tubes. The third is a separator, from whence the steam produced is taken and the overflowing water returned to the tubes. For this purpose large external tubes connect the separator to the cylinders forming the base, and between these cylinders the fire-bars are arranged with a firebrick bridge on either side protecting the cylinders from excessive heat. The fire-doors are situated at one end of the tunnel or arch of tubes, and the other end is closed principally by blocks of light fire-resisting brick inclined away from the fire to add to their durability.

The water-level in the boiler is best a little below the centre line of the separator, in which is placed, underneath the points where the tubes enter, a shield, to guide the circulating water down to the water-surface, at the same time protecting from spray a perforated pipe in which the steam is collected.

All the essential parts of the boiler have now been given. The

ends of the boiler are covered with plating, and, in order to make the casing quite smoke-tight, the outer wall of tubes is also covered with light plating, but this has not to resist any great heat.

The first water-tube boiler put into a torpedo-boat by the Author's firm afforded a very satisfactory means of comparison between the new boiler and its locomotive rival, which had been placed in a sister vessel.

The result of steaming was eminently satisfactory, and the saving in fuel at equal speeds was sufficiently evident without exact experiment, the boat under natural draught being about 1 knot an hour faster than the other vessel, the full-power trials showing also a difference of 0·67 knot speed in favour of the former. Some evaporative trials were made by the Portsmouth authorities, and the results seemed to indicate that equal duty could be obtained when the proportionate quantity of water evaporated was 2·36 from the water-tube boiler to 1·00 from the locomotive boiler. This boat has been at work for three years, and, with a view to ascertaining the state of the heating-tubes in the boiler, several tubes have been taken out. They afford a sample of tubes under varying conditions. Some were taken from the firebox, where they are exposed to the full intensity of the flame and radiant heat, some were from the flue, and some from the outer layer, which are exposed to more gentle heat through only one-half of their circumference. The condition of these tubes when cut open was found to be very satisfactory.

The small amount of scale in their interior is an important feature, and is a great contrast to the water-tubes taken from the boiler of the "Propontis" where the circulation was not so well provided for. The original thickness of the tubes was 15 B.W.G., and they have suffered no perceptible diminution. The interior surface is for the most part in excellent condition, but pitting does seem to have commenced slightly in the upper part of some of the tubes, though not sufficiently to show any reduction of thickness where a pit has been cut through in dividing the tube. It should be observed, in connection with this pitting, that zinc blocks were not put into the boiler until it had been working for about ten months.

A few of the outer tubes are much corroded on their external surface, but it is worthy of particular note that these are the tubes least exposed to the action of the fire, and that the damage is due to some cause independent of the stress to which the boiler is subjected while at work. It is, in fact, caused by the outside of the tubes having been wet and not to the action of the fire. The

boiler shown in Plate 1, Fig. 8, has been at work for five years, and it continues in excellent condition, no leak having appeared in any of the tubes, which are of steel. In the case, however, of some boilers built much more recently there has been trouble from pitting, and also from corrosion of the outer surface.

The pitting may be due to the presence of globules of lead left in the tubes from the process of bending. The uncertainty which arises from the use of iron or steel seems to make it desirable to employ brass or copper for these tubes, and experiments have been made with both these materials. Brass has given decidedly superior results; the surface of the copper tubes, when exposed to intense heat, had become somewhat rough, showing that the metal had suffered some loss; while the brass tubes retained a surface so smooth that it was not conceivable that any appreciable amount of metal was gone.

It has been suggested that brass tubes would suffer in the part of the boiler above the level of water-mark in the separator; but the most careful examination has failed to discover any sign of injury at this part, although in the experimental boiler, which was not designed for economy of fuel, the products of combustion were at a very high temperature even above the highest part of the generating tubes. The result of the experiments has been to induce the Author's firm to use brass for these tubes in all the boilers now under construction. The highest pressure hitherto used in these boilers has been 250 lbs. per square inch.

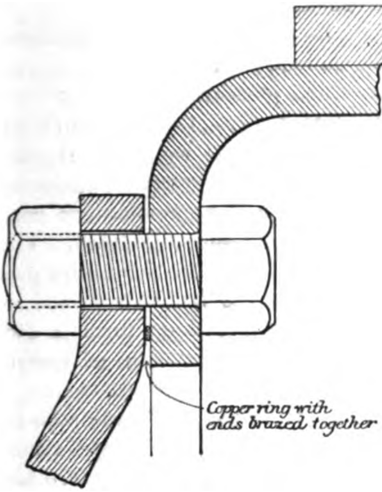
Ordinary steam-pipe joints are not suitable for this high pressure, and the Author is indebted to Mr. Perkins for a very concise description of a suitable joint. He said, "It must be metal, and it must be narrow."

In making a steam-tight joint with metal, two courses are open. The one is to use accurately fitted surfaces of considerable extent on flanges of great rigidity, or, if not of great rigidity, so secured that their elasticity has an equal effect throughout their circumference. The accurately fitted joint is necessarily expensive. The other method is to use a narrow metal joint upon which the intensity of pressure can be made so great that a continuous line of contact may be produced independent of any small irregularities. *Fig. 2*, p. 55, shows the form of joint employed.

With 200 lbs. pressure per square inch used with some boilers previously constructed, no great difficulty was found with the water-glasses, but the addition of another 50 lbs. seems to overtax them. This difficulty was overcome by the substitution of talc for glass, as had already been done by Mr. Perkins.

Experiments on evaporation were made with one of the larger boilers by measuring the feed-water from tanks and weighing the coal consumed, the steam produced being allowed to escape from the safety-valves. The duty obtained appeared to be very high, and clearly indicated that more carefully conducted experiments were necessary to give sufficient weight of evidence to establish the truth of so unusual a performance. Experiments have since been made by Professor Kennedy, which although not quite bearing out the first trial very nearly do so. It is well known that in a torpedo-boat, where engines of considerable

Fig. 2.



STEAM JOINTS FOR WATER-TUBE BOILER. WORKING PRESSURE 250 LBS.

power are compressed into very little space, there is no room to spare, and the Author was by no means sanguine that it was possible to make measurements. These, however, have been successfully accomplished by Professor Kennedy, enabling him to give a balance showing what was spent and how it was expended. The Author wishes to point out that, if this can be done for powers of over 700 HP. on a torpedo-boat, the difficulties are much less on larger vessels; and that trials of this kind may be made with advantage on board some of the vessels in Her Majesty's Navy.

The measurement of water returned from the engines to the boiler presented the greatest difficulties, the space available for the temporary tanks used for this purpose being so small that they were

filled in a very short time; but they were so ingeniously arranged, with conical tops and bases, that any considerable error in measurement was not possible. In the first experiments, the feed-pumps took their supply directly from the measuring-tanks. This, however, caused inconvenience in the stoke-hold; for the limited water-space in the boiler renders it specially sensitive to failure in water-supply, and this arrangement precluded any proper control. Also, when working at small power, the water was sent into the boiler much too rapidly, causing a fall in the steam-pressure, and then, while the other tank was filling, there was a long pause when no water could be obtained. The difficulty was overcome by putting a temporary tank in the stoke-hold, into which the water was pumped after being measured. A donkey-pump then pumped the water to the boilers as required.

The Author has much pleasure in bringing before the Institution the diagrams, Plate 3, Figs. 1 to 11, which are simply copies of those accompanying Professor Kennedy's report. In the trials referred to in the report, as Professor Kennedy explains, only one boiler was used; at the same time the combined economy of engines and boiler has been calculated. The result is, that when a point is reached in which the engines may be expected to work economically, the one boiler is forced much beyond its most economical rate of evaporation; for it is evident that when two boilers are used double the amount of steam can be supplied to the engines for a given rate of evaporation. Again, the air-pressure of 2 inches used in trial "E" was a test beyond the rate of working for the maximum HP. With this air-pressure sufficient steam was supplied by the single boiler for 770 indicated HP., but when both boilers were working together the greatest demand made upon each was limited by the size of the engines to produce steam sufficient for 650 indicated HP. This could be obtained with a wind-pressure of $1\frac{1}{4}$ inch.

The Paper is accompanied by several drawings and tracings, from which Plates 1, 2 and 3 and the Figs. in the text have been engraved.

[APPENDIX.

APPENDIX.

[*COPY.*]

3, Princes Street,
Westminster, S.W.
24th January, 1889.

Messrs. John I. Thornycroft & Co.,
Chiswick.

TORPEDO-BOAT BOILER AND ENGINE TRIALS (Plate 3).

Dear Sirs,—I have now pleasure in giving you a statement of the results of the five trials of the Thornycroft boilers and torpedo-boat engines which I made at your request in November last.

I have made five experiments in all—two with natural draught, one with about a ¼ of an inch of air-pressure in the stoke-hold, one with about ½ an inch air-pressure, and one with about 2 inches of air-pressure. I have distinguished these trials by the letters "A" to "E," in the order in which they were carried out, namely trial "A" on 21st November, 1888, trial "B" on 22nd November, trial "C" on 24th November, trial "D" on 26th November, and trial "E" on 29th November. It will, however, be more convenient to take them in an order corresponding to the air-pressure in the stoke-hold, and in what follows I have therefore done this. Before going on to describe any of them, however, I may state briefly the methods adopted.

Observations in Boiler Trials.

The essential matter to be experimented upon was the behaviour of the boiler under different conditions.

I had the coal weighed roughly into sacks of 1 cwt. and ½ cwt. before going on board, and stowed in the stoke-hold in these sacks; each sack was weighed in the stoke-hole by a tested spring-balance before being emptied, and the weight of the sacks themselves was also afterwards determined. The water was measured in the engine-room on its way from the hot-well to the feed-pump. For this purpose two cylindrical tanks were used, each holding about 540 lbs. of water, and three-way cocks were arranged above and below these tanks, so that one of them could always be receiving the delivery from the pump while the other was in communication with the feed-pump and therefore being emptied. The tanks were filled up to a marked height on a glass water-gauge, and when empty were completely drained by the lower cock. The possible error in filling was very small, amounting to only 1½ lb. of water for a range of 4 inches on the gauge, 2 inches above and 2 inches below the mark. As it was quite easy to keep the water-level within this range during the trials, the probable error due to over or under filling is practically nil. The feed-pump could always empty one tank in less time than the air-pump could fill the other. In trials "A" and "B" the feed-pump delivered direct into the boiler as usual, in the other trials the feed-pump delivered into a small open tank holding about 50 gallons placed in the stoke-hold, and the actual feeding of the boiler was done by a donkey in

the stoke-hold. This was done in order to facilitate the keeping of the water in the boiler at the right level, which would otherwise have been somewhat troublesome under the trial conditions. The levels of the water in the boiler itself, as well as in this auxiliary tank, were always made the same at the beginning and the end of each trial. The temperature of the feed, the height of the water in the glass, the pressure in the boiler, and the air-pressure and temperature in the stoke-hold, were noted every five minutes continuously throughout most of the trials, and in all cases every ten minutes. Arrangements were made for collecting samples of chimney gases, and for taking the temperature of those gases. This latter was noted every quarter of an hour, the thermometer used being a mercury thermometer containing compressed nitrogen over the mercury. The samples of chimney gases were collected about every hour by Mr. C. J. Wilson, F.C.S., and were afterwards analyzed by him at University College, London. Samples of the coal, which was "Nixon's Navigation," were collected on every trial. All the samples were subsequently mixed together, and resampled, and duplicate analyses made of the coal; this work was also done by Mr. Wilson, who also determined the calorimetric value of the coal by direct experiment. Samples of the ash were also collected and analyzed. The measurements thus made have sufficed to enable me to give you a detailed account of the expenditure of heat in and about the boiler in each of the trials.

The torpedo-boat tested (No. 258) had two boilers; one of them was entirely disconnected and not used at all; the tests were made entirely on the forward boiler, and in all the following particulars about the behaviour of the engines and boat, it must be remembered that only steam from one boiler was used.

In every trial a running start was made, as the boiler was so sensitive to changes in the fire or feed that greater error would have been introduced by the irregularities consequent on drawing the fire than were at all likely to follow the method adopted. The boiler and engines were allowed to work in the normal conditions of the trial for some little time before the start. The fire was then allowed to run itself as low as was consistent with the maintenance of the steam-pressure. The ashpit was cleared, and there was a weighed quantity of coal placed upon the stoke-hold floor. At a given signal the height of water in the gauge-glass was marked, as well as the level of water in the auxiliary tank, and the first portion of the weighed coal was put upon the fire. The time was noted at which each weighed quantity of coal was entirely put upon the fire, and until this happened no more coal was weighed out on the floor. The signal for ending the trial was given at a time, as near as possible to the intended duration of the trial, when all the conditions as to water-level, &c., were the same as those at the start. The diagrams of the trials show to what extent the coal consumption was constant throughout the whole of the trial, and afford, perhaps, the best test of the extent to which any difference in the state of the fire at start and finish could affect the result. It was intended always to begin and end with a falling pressure, and this was done as far as possible, but it was not found possible in every case.

Observations in Engine Test.

As it was not possible to test the boilers without running the engines, it was thought advisable and interesting to obtain all the particulars about the working of the engines that could be measured during each trial. The method of measuring the feed-water has already been described. In addition to this indicator diagrams were taken at or about the middle of each twenty minutes (in some cases fifteen minutes) during each trial, the number of revolutions were

found from the counter, and the I.H.P. computed from each set of diagrams by taking into account the mean revolutions per minute during the period in which the diagrams were taken. As it was desired to keep the boiler-pressure the same in all cases, it was necessary in the low-power trials to throttle the steam very much on its way to the engines; the actual pressure available was, therefore, that given by the gauge attached to the high-pressure valve-chest. The reading of this gauge was noted every time diagrams were taken, as were also the gauges on the two receivers and the vacuum-gauge, as well as the engine-room gauge in connection with the boiler.

Boiler.

The boiler itself was one of Mr. Thornycroft's patent tubular boilers, having a heating-surface of 1,837 square feet and a grate-surface of 30 square feet. In trials "D" and "E," a portion of the grate was bricked up, so that it was reduced to 26·2 square feet.

Engines.

The engines were triple expansion, of your usual pattern, with cylinders 14, 20 and 31½ inches in diameter by 16 inches stroke; the piston-rods were 2½ inches in diameter. All three cylinders were jacketed. The feed-pumps were driven by the main engine. Separate engines were employed to drive the circulating pump and for the fan. The boiler supplied steam for these engines as well as for the main engine, and also for the donkey-engine and the steering engine. All the separate engines, except the steering engine, drained back into the condenser, so that the water-supply was not lost. Taking the whole experiment as a *boiler* trial this is, of course, of no importance, but taking it as an engine trial it must be remembered that the total feed-water includes that required for all the auxiliary engines, while, of course, the I.H.P. belongs to the main engines alone. The donkey-engine piston leaked considerably, especially upon trial "D," when its work was lightest, and the steering engine also lost some steam by leakage, so that the figures as given below, representing feed-water used per I.H.P. per hour, are very much larger than correspond to the real consumption of the main engines.

Coal.

The following is the analysis by Mr. Wilson of the coal used in the trials:—

Constituents.	Percentage.
Moisture	0·96
Ash	2·19
Carbon	87·76
Hydrogen	4·11
Sulphur, nitrogen and oxygen, by difference	4·98
	100·00

I find by calculation that this fuel has a calorific value of 14,900 thermal units per lb., which is equal to that of 1·025 of a lb. of carbon. Each lb. of coal is therefore capable, if completely burnt, of evaporating 15·41 lbs. of water from and at 212° Fahrenheit. Mr. Wilson has made for me a direct determination of the calorimetric value of the fuel in a carefully tested calorimeter; this experiment shows the value of the fuel to be 15,450 thermal units per lb., which corresponds to 15,020 thermal units per lb. if the steam formed passes away in a

gaseous condition. This value is only about 1 per cent. in excess of that due to calculation, a most satisfactory agreement. Each lb. of fuel requires 11·5 lbs. of air, theoretically, for its perfect combustion.

The analysis of the ash shows it to consist of 86·5 per cent. of carbon, and 13·5 per cent. of inorganic and incombustible matter. (By ash, I here mean the material which fell through the grate bars into the ashpit during the trial.)

The leading particulars of all five trials are given in Tables I and II.

Trial "A," 21st November, 1888. Natural Draught.

This trial was the first in order, and may be taken as being rather in the nature of a rehearsal than a complete trial, but so many observations were made that I have thought it worth while to work out the results as completely as was possible. The trial lasted about five hours. The stoke-hold was open. The mean boiler-pressure was 186 lbs. per square inch above the atmosphere, and the coal burnt was 334 lbs. per hour, or 11·1 lbs. per square foot of grate-surface per hour. The feed-water measurement on this trial was unfortunately rendered untrustworthy by an accident. The engine ran at 192·8 revolutions per minute, the pressure in the HP. valve-chest being only 50·6 lbs. per square inch. The I.H.P. was 150·3. The total coal put upon the fire amounted to 2·22 lbs. per I.H.P. per hour, but in this case none of the ash (which it will be seen contained over 85 per cent. of carbon) was re-used. The ash amounted to just 16 per cent. of the whole weight of the fuel.

The samples of furnace gas collected during this trial were analyzed with the following results:—

Constituents.	Percentage by Volume.	Percentage by Weight.
CO_2	8·58	12·63
CO	0·39	0·37
O	10·71	11·47
N	80·52	75·33
	100·00	100·00

Calculation from this analysis shows that about 24 lbs. of air per lb. of coal were used; that is about 2·1 times the quantity theoretically required.

Trial "D," 26th November, 1888 (Plate 3, Fig. 3). Natural Draught.

This trial lasted 4 hours 57 minutes. The stoke-hold was open, the mean boiler-pressure during the trial 181·8 lbs., and the coal burnt per hour 203·3 lbs., or 7·74 lbs. per square foot of grate per hour. The feed used per hour was 2,281 lbs., which corresponds to an actual evaporation of 11·22 lbs. of water per lb. of coal. The temperature of the feed was, however, 76°·3 Fahrenheit, while the temperature of the steam was 380°·2, so that reduced to standard the evaporation was 13·40 lbs. of water per lb. of coal. The ash which fell through the grate amounted to about 47 lbs. per hour; this very large percentage being, of course, due to the very thin fire that had to be kept up on the grate. The whole of this ash was put back again on the grate, about a quarter of it in the fourth hour, and the remainder in the last hour. The coal line in the diagram of this trial shows very clearly its use as fuel.

The detailed analyses of the chimney gases are given in the appendix to this report; the following is their mean:—

Constituents.	Percentage by Volume.	Percentage by Weight.
CO_2	11·74	17·10
CO	0·10	0·10
O	7·71	8·20
N	80·45	74·60
	100·00	100·00

The analyses given in this and all other similar tables are those of the gas in a dry condition, that is free from water vapour. I did not attempt to find out the weight of moisture in the gases by direct experiment. This omission does not sensibly alter the calculation by which the weight of air per lb. of carbon or coal is obtained; its greatest effect is to make a small difference in the specific heat of the gas. For example, the specific heat of the dry gas in trial "B" is 0·238, whereas the presence of gaseous steam, due to the hydrogen in the fuel, would increase this to 0·242. The mean specific heat of the gases has been taken as 0·24 in all cases.

I find that the above analysis corresponds to only 18·14 lbs. of air per lb. of coal, which is 1·62 time the quantity theoretically required, but it will be noted that although the quantity of air is so small the combustion was very nearly perfect, only one of the samples collected showing any carbonic oxide.

The heat of the fuel goes in greatest part to the heating and evaporation of water. The remainder partly heats the furnace gases, partly is lost by imperfect combustion and partly by radiation and other causes. I attempted to determine the loss by radiation, as I have been able to do approximately in some cases, by finding the amount of coal which it was necessary to burn in order to keep up the steam-pressure in the boiler, no steam being allowed to leave the boiler, and no water being put into it. The quantity, however, was so small that the errors in its measurement due to burning it in such a large grate prevented my obtaining any satisfactory results.

The following short Table shows the way in which the heat of combustion was utilized by the boiler. It is perhaps unnecessary that I should give the calculations in detail:—

	Per cent.
Heat expended in heating and evaporating feed-water .	86·8
„ „ in raising temperature of furnace gases	10·8
„ lost through formation of carbonic oxide . . .	0·5
„ „ by radiation and otherwise unaccounted for .	1·9
	100·00

The small loss in furnace gases corresponds to their very low exit temperature, namely, 421° Fahrenheit.

The very high percentage of evaporation, 86·8, represents the efficiency of the boiler, and is of course simply equal to the ratio between the actual evaporation and that theoretically due to the perfect combustion of the fuel, or $\frac{13\cdot4}{15\cdot4}$.

It is only right that I should say that this is the highest boiler efficiency I have ever found upon any trial with which I have had to do, if indeed it be not, as I almost think it is, the highest on record in any trustworthy manner.

As regards the working of the engines on this trial, I can give you the following particulars:—

The engines ran at 165·2 revolutions per minute, but in order to keep the power down sufficiently it was necessary so to throttle the steam that the pressure

in the high-pressure valve-chest was only 22·7 lbs. per square inch above the atmosphere. As the engines are intended to work also with a pressure of 200 lbs. per square inch in the valve-chest, it is a matter of some curiosity to examine their behaviour under these very special conditions. The mean pressure in the HP. cylinder was 13·0 lbs. per square inch, in the MP. cylinder 9·5 lbs. per square inch, while in the LP. cylinder it was only 2·2 lbs. per square inch. The vacuum was 27·97 inches of mercury, which on the day of trial corresponded to an absolute pressure of 0·79 lb. per square inch. The total feed-water per I.H.P. per hour (that is, as already explained, the total feed-water per hour used for all purposes divided by the total I.H.P.) was 25·6 lbs., the I.H.P. being only 89·1. The coal per I.H.P. per hour was 2·28 lbs. The water coming from the jackets was collected and measured separately before being returned to the feed measuring tanks, it amounted to 5·6 per cent. of the whole feed-water. The leakage through glands, &c., together with the non-return to the condenser of the steam which passed to the steering-engine, made it necessary to add a little water from time to time in order to keep the water at its proper height in the boiler. This added feed was separately weighed before being poured into the hot-well (through which it passed to the measuring tanks), and amounted to 0·57 per cent. of the whole feed.

TRIAL "C," 24th NOVEMBER, 1888 (PLATE 3, FIG. 2). AIR-PRESSURE IN STOKE-HOLD, 0·27 INCH.

In this trial it was intended to keep the air-pressure in the stoke-hold as nearly ¼ inch of water as possible. The actual average pressure during the trial, which lasted five hours and nine minutes, was 0·27 inch. The average boiler-pressure was 171·2 lbs. per square inch above the atmosphere, and the atmospheric pressure for the day was 14·8 lbs. per square inch. The coal burnt per hour was 559 lbs.; the rate of combustion being therefore 18·6 lbs. of coal per square foot of grate-surface per hour. The ash which fell through the grate during the trial amounted to 6·8 per cent. of the weight of coal, but was nearly all put back on the fire before the end of the trial.

The feed-water evaporated amounted to 5,852 lbs. per hour, the feed temperature being 78° Fahrenheit, and the steam temperature 376° Fahrenheit. The actual evaporation per lb. of fuel was therefore 10·48 lbs. of water, which reduced to standard amounts to 12·48 lbs. of water, per lb. of coal. The air-pressure in the chimney, measured close to the place at which the furnace gases were collected, was 0·03 inch of water. The mean temperature of the chimney gases was 540° Fahrenheit. By a most unfortunate accident to the case containing the furnace gas sampling bottles, these were all broken, so that I am not able to give the analysis of the furnace gases for this trial. The results, however, from trials "D" and "B," between which this trial lies, allow a fairly accurate estimate to be made of the quantity of the furnace gases. In trial "D," with natural draught, 18·1 lbs. of air were used per lb. of coal; in trial "B," with ½ inch of pressure in the stoke-hold, 17·4 lbs. of air were used per lb. of coal. It cannot be far wrong therefore to take the consumption of air per lb. of coal in trial "C" as about 17·8 lbs. The heat balance for this trial will therefore stand thus:—

	Per cent.
Heat expended in heating and evaporating feed-water .	81·4
,, ,, in raising temperature of furnace gases.	15·0
,, lost by radiation, imperfect combustion and otherwise unaccounted for	3·6

The mean speed of the engines during the trial was 234·2 revolutions per minute, the pressure in the HP. valve-chest was 79·2 lbs. per square inch, and the total I.H.P. 282·1. The total feed-water per I.H.P. per hour was 20·74 lbs., of which 4·0 per cent. came through the jackets, and 0·76 per cent. was added to make up for losses as before described. The consumption of fuel per I.H.P. per hour was 1·98 lb.

TRIAL "B," 22nd NOVEMBER, 1888 (PLATE 3, FIG. 1). AIR-PRESSURE IN STOKE-HOLD, 0·49 INCH.

In this trial the air-pressure in the stoke-hold was kept about double that of trial "C," namely at 0·49 inch of water. The boiler-pressure, however, was lower than on the other trials, namely, 149·4 lbs. per square inch. The trial lasted four hours, and 894 lbs. of coal were burnt per hour, or 29·8 lbs. per square foot of grate per hour. The feed-water measurement on the 22nd November was unfortunately rendered useless by a defect in the apparatus. As, however, the whole of the other measurements were made, and were very complete, I thought it worth while to attempt to supply the defect at a later trial. On the 29th November the engines were run for an hour at the same speed and at the same I.H.P. as in "B," and the feed measurements during this hour have been taken to represent those throughout the whole of trial "B." It was fortunately possible to imitate the conditions of trial "B" with great accuracy. The revolutions per minute were 269·3 instead of 268·7, the I.H.P. 442 (from four sets of diagrams) instead of 449 (from twelve sets of diagrams). The feed-supply during the hour's run was so constant that each quarter of an hour gave practically the same figures. Under these circumstances, I have had no hesitation in accepting the water measurement made on the 29th November as accurately representing the water used on the 22nd. The feed-water used per hour amounted to 8,583 lbs., its mean temperature was 83°·8 Fahrenheit, and the temperature of the steam was 365°·5. *None* of the ash which fell through the bars on this trial was re-used, and under these conditions the actual evaporation was 9·6 lbs. of water per lb. of fuel, which amounts to 11·35 lbs. under standard conditions. Had the ash been used again, as on the other trials, these figures would have been respectively about 10·2 and 12·0 lbs. The mean temperature of the chimney gases was 610° Fahrenheit, and the mean chimney pressure shown by the U gauge was 0·12 inch of water. The mean analysis of the furnace gases is as follows, five samples having been taken during the trial:—

Constituents.	Percentage by Volume.	Percentage by Weight.
CO_2	11·68	17·00
CO	0·62	0·58
O	7·41	7·82
N	80·29	74·60
	100·00	100·00

This analysis corresponds to 17·4 lbs. of air per lb. of coal. The heat balance, allowing for the non-burning of the ashes, was as follows:—

	Per cent.
Heat expended in heating and evaporating feed-water	78·2
Heat expended in raising temperature of furnace gases	16·5
Heat lost by formation of CO	5·0
Heat lost by radiation and otherwise unaccounted for	2·3

The speed of the engines in this trial was 268·7 revolutions per minute. The mean steam-pressure in the HP. valve-chest was 120·7 lbs. per square inch; the I.H.P. was 449·2. The total feed-water per I.H.P. per hour works out to 19·1 lbs., of which 2·2 per cent. passed through the jackets, while 1·03 per cent. was added to make up losses. The fuel used (not allowing for ash) amounts to 1·99 lb. per I.H.P. per hour, which would have been reduced to about 1·88 lb. if the ash had been burned.

TRIAL "E," 29TH NOVEMBER, 1888 (PLATE 3, FIG. 4). AIR-PRESSURE IN STOKE-HOLD, 2 INCHES OF WATER.

This was the last trial which time allowed to be carried out, and the average air-pressure was 2 inches. It was practically a full power trial for the boiler under these conditions, the stoking being almost continuous, and the vessel being driven about 18 knots (mean of four runs on mile) continuously. The trial lasted two hours only, which was considered sufficiently long under such forced conditions. It will be seen from the diagrams that water and coal were used throughout at a practically uniform rate, so that the accuracy of the trial has not suffered in consequence of its comparatively short duration. The mean boiler-pressure was 180·5 lbs. per square inch, and the coal burnt per hour 1,751 lbs., or 66·8 lbs. per square foot of grate per hour. The whole of the ash, about 5½ per cent. of the fuel, was reburned. The feed used per hour was 15,554 lbs. its mean temperature being 111°·2 Fahrenheit, while the mean temperature of the steam was 379°·6 Fahrenheit. The actual average evaporation was therefore 8·89 lbs. of water per lb. of fuel, or 10·29 lbs. per lb. reduced to standard. The air-pressure in the chimney was 0·4 inch of water, the mean temperature of chimney gases being 777° Fahrenheit. The following is the mean analysis of three samples of gases taken during this run:—

Constituents.	Percentage by Volume.	Percentage by Weight.
CO_2	12·60	18·40
CO	2·30	2·15
O	4·45	4·15
N	80·65	75·30
	100·00	100·00

From these results I calculate that the weight of air used per lb. of coal was about 17·2 lbs. The heat balance was as follows:—

	Per cent.
Heat expended in heating and evaporating feed-water	66·6
Heat expended in raising temperature of furnace gases	20·3
Heat lost by imperfect combustion or by formation of carbonic oxide	9·2
Heat lost by radiation and unaccounted for	3·9
	100·0

The speed of the engine during trial "E" was 318·4 revolutions per minute, and the mean pressure in the HP. valve-chest 168·4 lbs. per square inch. The I.H.P. (eight sets of diagrams) was 775. The vacuum which had been about 28 inches in the three former trials, fell, not unnaturally, to 25·2 inches of mercury. The total feed-water per I.H.P. per hour was 20·08 lbs., of which the

jacket-water amounted to 1·9 per cent., while 0·93 per cent. was added to make up for losses. The fuel used per I.H.P. per hour was 2·25 lbs.

Comparison of Results.

Tables I and II contain the various figures given above, along with a number of others which are of interest, and in addition to these I append tables containing details furnished me by Mr. C. J. Wilson of the furnace-gas analyses, and also the coal and ash analyses. The former are specially interesting as showing within what limits gases collected on one and the same trial are likely to vary. It will be noticed that the variation is very much greater, as might well be expected, upon a light power trial "D" than upon the heavy power trial "E." I append also to this report diagrams showing graphically the progress of each of the four trials lettered "B" to "E" (Plate 3, Figs. 5 to 11). These diagrams do not require any further explanation. I append also some other diagrams which you may find of interest. Diagram 5 shows graphically the four "Heat Balances" in relation to the pressure of air in the stoke-hold; it will be seen that the percentage unaccounted for varies very little in the four cases, and that the fall in boiler efficiency is obviously due to the less perfect combustion, and the greater amount of heat carried away by the furnace gases. Some of these matters are made still more plain by diagrams 6 and 9. Here the base of the diagram is made proportionate to the air-pressure in the stoke-hold, while above it are plotted for each trial the chimney-gas temperatures, the quantity of air used per lb. of fuel, etc. Diagrams 7 and 8 show in similar fashion the composition of chimney gases, while diagrams 10 and 11 show the principal quantities measured during the trial in their relation to the coal burnt per hour.

I have already remarked on the most notable evaporating efficiency of Mr. Thornycroft's boiler when working at very low powers. The manner in which it retains that high efficiency when doing seven times as much work is, perhaps, equally remarkable. That one and the same boiler should be able to supply steam for powers varying from 90 to 770, maintaining so high an average efficiency throughout the whole range, is a most remarkable result, and one on which you may fairly be congratulated.

The change from a smaller to a greater power can be carried out with very great ease. I found, for instance, on the 28th November, that I had the engines working *steadily* under the conditions of trial "E" in considerably less than fifteen minutes after they had been working *steadily* under conditions similar to those of trial "B."

Faithfully yours,

(Signed) Alex. B. W. Kennedy.

[Appendix.

APPENDIX.

Detailed Analyses of Chimney Gas and Analyses of Coal and Ash.

Chimney Gases. Trial A. November 21st, 1888.

Sample taken at	2.5 P.M.	4.5 P.M.
	Per cent.	Per cent.
Carbonic Acid	8·22	8·95
Carbonic Oxide	0·00	0·78
Oxygen	11·57	9·85
Nitrogen	80·21	80·42
	100·00	100·00

Chimney Gases. Trial B. November 22nd, 1888.

Sample taken at	12.20 P.M.	1 P.M.	1.40 P.M.	2.30 P.M.	3.30 P.M.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Carbonic acid	11·83	13·75	8·09	13·08	11·67
Carbonic oxide	0·00	0·72	0·70	(0·63)[1]	1·05
Oxygen	7·73	5·14	11·15	5·95	7·06
Nitrogen	80·44	80·39	80·06	(80·34)[1]	80·22
	100·00	100·00	100·00	100·00	100·00

Chimney Gases. Trial D. November 26th, 1888.

Sample taken at	11.30 A.M.	12.30 P.M.	1.30 P.M.	2.30 P.M.	3.30 P.M.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Carbonic acid	13·16	13·32	9·66	12·34	10·19
Carbonic oxide	0·52	0·00	0·00	0·00	0·00
Oxygen	5·57	6·64	10·01	6·97	9·37
Nitrogen	80·75	80·04	80·33	80·69	80·44
	100·00	100·00	100·00	100·00	100·00

Chimney Gases. Trial E. November 29th, 1888.

Sample taken at	1 P.M.	2 P.M.	2.43 P.M.
	Per cent.	Per cent.	Per cent.
Carbonic acid	12·51	12·47	12·81
Carbonic oxide	2·11	2·01	2·76
Oxygen	4·16	5·05	4·16
Nitrogen	81·22	80·47	80·27
	100·00	100·00	100·00

[1] The carbonic oxide was not determined separately in this case; the nitrogen and carbonic oxide together amounted to 80·97 per cent.

Analysis of Coal Used.

(Described as Nixon's navigation steam coal.)

	Per cent.
Moisture	0·96
Ash	2·19
Carbon	87·76
Hydrogen	4·11
Sulphur, Nitrogen, Oxygen } by difference	4·98
	100·00

Calorific value of coal determined by experiments in a modified Thompson's calorimeter = 15·99 lbs. of water evaporated from and at 212° Fahrenheit per lb. of coal. This is equivalent, as explained in Report, to an evaporation of 15·54 lbs. of water from and at 212° Fahrenheit if the water of combustion be rejected (as in the trials) in a gaseous and not in a liquid condition.

Analysis of Ash.

	Per cent.
Moisture	4·24
Loss on burning	82·78
Ash	12·98
	100·00

All the above analyses were made for me by Mr. Charles J. Wilson, F.I.C., F.C.S., of University College.

TABLE I.

		A.	D.	C.	B.	E.
1	Date	21st Nov., 1888	26th Nov., 1888	24th Nov., 1888	22nd Nov., 1888	29th Nov., 1888
2	Duration	5 hours 2 minutes	4 hours 57 minutes	5 hours 9 minutes	4 hours	2 hours
3	Atmospheric pressure	14·80 lbs. per sq. in.	14·55 lbs. per sq. in.	14·80 lbs. per sq. in.	14·84 lbs. per sq. in.	14·45 lbs. per sq. in.
4	Boiler-pressure	186·00 „ „ „	181·80 „ „ „	171·20 „ „ „	149·40 „ „ „	180·50 „ „ „
5	Boiler-pressure (absolute)	200·80 „ „ „	196·30 „ „ „	186·00 „ „ „	164·20 „ „ „	194·90 „ „ „
6	Air-pressure in stoke-hold	0·00	0·00	0·27 in.	0·49 in.	2·00 in.
7	Air temperature in stoke-hold	..	69°·3 Fahr.	71°·4 Fahr.	60°·3 Fahr.	62°·1 Fahr.
8	Total weight of coal put on fire	1,680·0 lbs.	1,006·5 lbs.	2,877·0 lbs.	3,575·0 lbs.	3,503·0 lbs.
9	Total weight of ashes	270·0 „	233·5 „	197·0 „	..	192·0 „
10	Weight of ashes put back on fire	None	233·5 „	170·0 „	None	192·0 „
11	Coal burnt per hour	334·0 lbs.	203·3 „	559·0 „	894·0 lbs.	1,751·0 „
12	Area of fire-grate	30 sq. ft.	26·2 sq. ft.	30 sq. ft.	30 sq. ft.	26·2 sq. ft.
13	Coal burnt per foot grate per hour	11·10 lbs.	7·74 lbs.	18·60 lbs.	29·80 lbs.	66·80 lbs.
14	Total feed-water used	..	11,291·7 „	30,141·0 „	34,332·0 „	31,109·0 „
15	Feed used per hour	..	2,281 „	5,852 „	8,583 „	15,554 „
16	Feed temperature	78°·4	76°·3 Fahr.	78°·0 Fahr.	83°·8 Fahr.	111°·2 Fahr.
17	Steam „	382° Fahr.	380°·2 „	375°·5 „	365°·5 „	379°·6 „
18	Factor of evaporation	1·192	1·194	1·191	1·182	1·158

19	Water evaporated per lb. fuel (ash not re-used) .	..	..	..	9·60 lbs.	..
20	Water evaporated per lb. fuel under ordinary conditions, with ash utilized	..	11·22 lbs.	10·48 lbs.	[10·20 „]	8·89 lbs.
21	Equivalent evaporation from and at 212° Fahr. (ash not re-used) . .	..	..	..	11·35 „	..
22	Equivalent evaporation from and at 212° Fahr., with ash burnt . . .	..	13·40 „	12·48 „	[12·00 „]	10·29
23	Equivalent evaporation from and at 212° Fahr. per lb. carbon, value in fuel	..	13·08 „	12·18 „	[11·70 „]	10·04
24	Temperature of gases in chimney	474° Fahr.	421° Fahr.	540° Fahr.	610° Fahr.	777° Fahr.
25	Air-pressure in chimney .	0·00 in.	0·00 in.	+ 0·03 in.	+ 0·12 in.	+ 0·40 in.
26	Total heating-surface . .	1,837 sq. ft.	1,837 sq. ft.	1,837 sq. ft.	1,837 sq. ft.	1,837 sq. ft.
27	Ratio of heating-surface to grate	61·2	70·1	61·2	61·2	70·1
28	Water evaporated per sq. ft. of heating-surface per hour	..	1·24 lb.	3·20 lbs.	4·70 lbs.	8·50 lbs.
29	Mean rate of transmission of heat per sq. ft. heating-surface per minute . .	..	23·8 heat units	61·0 heat units	89 heat units	158 heat units
30	Efficiency of boiler. . .	..	86·8 per cent.	81·4 per cent.	78·2 per cent.	66·6 per cent.

TABLE II.

		A.	D.	C.	B.	E.
1	Revolutions per minute	192·8	165·2	234·2	268·7	318·4
2	Steam-pressure in hp. valve chest above atmosphere	50·60 lbs. per sq. in.	22·70 lbs. per sq. in.	79·20 lbs. per sq. in.	120·70 lbs. per sq. in.	168·40 lbs. per sq. in.
3	Mean pressure, hp. cylinder	17·60 " " "	13·00 " " "	27·30 " " "	37·60 " " "	49·90 " " "
4	" " mp. "	13·70 " " "	9·50 " " "	20·10 " " "	27·20 " " "	40·20 " " "
5	" " lp. "	3·40 " " "	2·20 " " "	5·74 " " "	8·29 " " "	12·80 " " "
6	Mean vacuum	28·04 in. = 13·77 lbs.	27·97 in. = 13·74 lbs.	28·34 in. = 13·92 lbs.	28·06 in. = 13·78 lbs.	25·25 in. = 12·40 lbs.
7	I.HP., hp. cylinder	41·7	26·5	78·4	124·1	195·3
8	" mp. "	66·8	39·6	118·7	185·1	323·6
9	" lp. "	41·8	23·0	85·0	140·0	255·8
10	" total "	150·3	89·1	282·1	449·2	774·7
11	Total feed-water per I.H.P. per hour	..	25·60 lbs.	20·74 lbs.	19·10 lbs.	20·08 lbs.
12	Jacket water per hour	151·0 lbs.	126·0 "	236·5 "	188·5 "	292·5 "
13	" " " I.H.P. per hour	1·00 lb.	1·43 lb. = 5·60 per cent.	0·84 lb. = 4·03 per cent.	0·42 lb. = 2·20 per cent.	0·38 lb. = 1·90 per cent.
14	Added feed-water per hour	31·7 lbs.	12·9 lbs = 0·57 per cent.	44·6 lbs. = 0·76 per cent.	88·2 lbs. = 1·03 per cent.	145 lbs. = 0·93 per cent.
15	Lbs. of fuel per I.H.P. per hour	2·220 "	2·280 lbs.	1·981 lb.	1·990 lb.	2·260 lbs.
16	Lbs. of carbon value per I.H.P. per hour	2·280 "	2·334 "	2·030 lbs.	2·040 lbs.	2·320 "
17	Approximate speed of vessel on measured mile	11·8 knots	..	..	..	18·0 knots

Discussion.

Sir JOHN COODE, President, said that having regard to the exhaustive manner in which the Author had treated the subject, and more especially to the way in which he had dwelt upon and elucidated the principles involved, the Paper could not fail to be of great service to all who were concerned in the design or in the use of steam-boilers. Sir John Coode.

Mr. JOHN I. THORNYCROFT said there was only one remark he desired to make before the discussion commenced. He had been asked by several persons how tubes were fastened into the tube-plate. The mode adopted was simply that of using Dudgeon's mandril in the ordinary way; and in boilers in which the tubes were not sufficiently large for a man to get in, the mandril was worked by bevel-gearing. Mr. Thornycroft.

Professor ALEXANDER B. W. KENNEDY observed that at the end of the Paper there was an Appendix containing a statement giving the results of some experiments which he had made for the Author; and as, for obvious reasons, this statement had not been read, it might be convenient if he gave a few particulars of the results of some of the experiments described in it. Of course, so very novel a boiler might be regarded from various points of view. Its merits might be discussed from the point of view of cost and lightness, or from the cost of maintenance and ease of repairs; but the only matters on which he had occasion to examine it were with reference to its economy, that was its efficiency as a water evaporator. He had to do that under the most varying conditions, because a boiler of a torpedo-boat might have to exert powers that varied more widely than the powers of any corresponding land boiler, or indeed any other marine boiler. The trials he had to make were in fact a graduated series of trials at different air-pressures in the stoke-hold; a trial with natural draught, a trial with about $\frac{1}{4}$ inch air-pressure, a trial with $\frac{1}{2}$ inch, and a trial with about 2 inches air-pressure. He did his best to get all the measurements as complete as possible, and he believed that the figures obtained were as accurate as such figures could be, the errors being only such as would occur with the most careful measurements. He would not say anything about the methods of measurement, but would mention the results of two of the trials, the first with natural draught, and the second with 2 inches of air-pressure in the stoke-hold. In the first case, the boiler was Professor Kennedy.

Professor Kennedy. very much underworked, so to speak, and in the latter case it was very much overworked. In the first case it was evaporating about 1 ton of water per hour, and burning something under 8 lbs. of coal per square foot of grate; and in the second case it was evaporating 7 tons of water per hour, and burning nearly 70 lbs. of coal per square foot of grate; so that there was about nine times the rate of combustion in the second case that there was in the first. In reference to a remark made in the Paper, he might say that the stoke-hold was about 10° cooler in the latter trial than in the former trial. The volume of air blown into it, even with the pressure of 2 inches of water, was sufficient to keep down the temperature to 60° or 61°, while formerly it was 70°, 71°, or 72°; and the actual pressure was not so great but that it was possible to get in and out the stoke-hold by opening the doors, without the least trouble or without any interference with the regularity of work. The trial with a natural draught and with a very slow rate of combustion, namely, $7\frac{3}{4}$ lbs. of coal per square foot of grate, resulted in a figure which he did not hesitate to give, because he had no doubt it was right; but which he thought, at least as far as his experience went, was what was technically known as a "record," for he did not think any other trials had been made of any considerable length in which as much as, or at any rate more than, 13·4 lbs. of water had been evaporated by 1 lb. even of the very best coal. The coal used was of very high quality, so that that particular evaporation amounted to 86·8 per cent. of the whole heat of combustion. The coal was Nixon's Navigation coal, giving about 2 per cent. of ash. Plate 3, Fig. 5, showed clearly the results of the trials, this particular trial being represented by the left-hand vertical ordinates. The meaning of the area under each curve in the diagram was marked on it. The largest and lowest area showed the quantity of heat taken up by the feed-water; the area above showed the quantity of heat taken up in raising the temperature of the furnace gases; the area above that showed the heat lost by the formation of carbonic oxide, or by incomplete combustion; while finally the area at the top showed the total quantity that could not be accounted for. He supposed that when an evaporation of 13·4 lbs. of water per lb. of coal was suggested, the question whether there was any priming would naturally be asked. He knew of no method of measuring priming water with accuracy at sea, and he did not make any attempt to measure it. But as the boiler would without difficulty evaporate seven or eight times the amount of water which it was raising on that particular trial, he thought there was no

likelihood of there having been any priming. The boiler was underworked, and the quantity of water evaporated was very small in proportion to the power of the boiler. Two of the other trials he would pass over, but he might mention that the last trial with 2 inches of water-pressure in the stoke-hold gave the following results:—The same boiler with the same heating-surface and the same grate-surface as before had burnt 66·8 lbs. of coal per square foot of grate instead of 7¾ lbs., and evaporated 15,500 lbs. of feed-water per hour instead of 2,200 lbs.; and at the same time it realized an efficiency which, although not very high, was one that many land boilers working at only 10 lbs. of coal per square foot of grate did not reach. The 66·8 per cent. efficiency was represented by the height, on the right hand side of Plate 3, Fig. 5, of the lowest curve. Where the rest of the heat went was perfectly clear he thought from that diagram. In the first place a great deal more heat was spent in raising the temperature of the furnace gases, because their temperature was much higher. The details of trial E were shown by Plate 3, Fig. 4. The funnel temperature ran up to about 800° (it was shown by the sloping line at the top); whereas in trial D, Plate 3, Fig. 3, the funnel temperature was only about 400°, so that there was a much greater loss of heat in the chimney. Further, the combustion, as was not unnatural, was much less active in E than in D. In the natural-draught trial only a trace of carbonic oxide was formed, and the loss by incomplete combustion was very small; but in the 2-inch pressure trial (marked E) there was 2·3 per cent. of carbonic oxide, and therefore a considerable amount of heat was lost by incomplete combustion. That, of course, was the price paid for multiplying the duty of the boiler by seven or eight. It happened that several of the curves upon Plate 3, Figs. 9 and 6, were nearly parabolic in form, which meant that several of the quantities concerned varied nearly as the square root of the air-pressure. The coal burnt per hour per square foot of grate was nearly equal to $40 \sqrt{p} + 0·07$ lb., where p stood for the air-pressure measured in inches of water. The rate of transmission of heat through the tubes was very nearly $105 \sqrt{p + 0·07}$ heat units per square foot per minute, and the equivalent evaporation per square foot of heating-surface per hour was nearly $6·5 \sqrt{p + 0·07}$ lb. of water from and at 212° Fahrenheit, while the heat wasted from all causes varied somewhat in the same fashion. The figures coming out in that way might serve as a guide for continued work in the same direction, but of course the particular constants belonged to the particular boiler tested. The Author had placed upon the wall practically

Professor Kennedy.

Professor Kennedy. all the particulars which he had supplied him in his report. It was only right that he should say, with reference to Table II, which gave the results of working with the engine, that those results must not be criticized without knowing exactly what they meant. The eleventh line in Table II gave the total feed-water per indicated HP. per hour. It began at 25·6 lbs., which might seem very large indeed for any engine on board ship. The reason was simply this: the boiler was working at about 180 lbs. per square inch, but the steam produced at that pressure was much more than was necessary to keep the boat going as fast as she required to go on that occasion, which was considerably faster than ordinary boats went. The consequence was that the steam-pressure in the valve-chest was under 23 lbs., so that the engine that used 25 lbs. of water per HP. was not an engine working at 180 lbs. of steam, but at 23 lbs. of steam. When the steam-engine was working at 79 lbs. of steam, it used 20 lbs. of feed-water; when working at about 121 lbs. of steam, or 169 lbs., it used somewhere about the same. He ought further to say that the experiments were, as explained in his report, boiler-experiments, and not engine-experiments, and that the figures given for feed-water included the water which went to the steering engine and to sundry other machines on board, although the power included only the power from off the main engine. It was not possible to separate the quantities of steam that went to those smaller engines, and in that way the main engines were made to appear less economical than they actually were. He would only say further that he had congratulated, and he now again congratulated, the Author very heartily, on having produced a boiler which could not only attain such a large economy over long and rigorous trials, but so large an economy over a very wide range of work, a thing which, he thought, had rarely been done, or even attempted.

Mr. Yarrow. Mr. A. F. YARROW, after acknowledging the obligation which he felt the Institution was under to the Author for bringing forward so freely the results of his experience, coupled as it was with detailed data of the important trials conducted by Professor Kennedy, remarked that the Author had briefly referred to the boilers of the "Propontis," which vessel had been navigated for some time, but ultimately the boilers were removed. They were of the Rowan and Horton's design, and were built by Messrs. Elder and Co. The engines were triple expansion, and the first on that system which Mr. Kirk had constructed. The cause of the ultimate failure of the "Propontis" boilers had been described to the Institute of Engineers in Scotland ten years ago by Mr. Kirk, who stated that

several of the boilers were grouped together, working as one, by connecting the water chambers by large horizontal water-pipes, and uniting the steam-chests by the usual steam-pipe.[1] That arrangement caused excessive fluctuations of water-level; but the reason of this was not discovered till after the ship had been to sea for the best part of two years. The result of that unfortunate connection was that the water was driven out of those sections where the fires were forced to the greatest extent into the adjoining sections, and the fluctuation frequently amounted to as much as 5 feet. Mr. Kirk attributed to that defective feature in the design all the subsequent troubles and mishaps. The other difficulty met with was the rapid pitting. How far pitting was due to the fluctuations of water-level, which caused the tubes to get overheated one minute and then suddenly cooled the next, was a matter of doubt; but it was not unnatural to expect that the pitting action was greatly accelerated thereby. In 1876 Mr. Rowan introduced an improvement in that type of boiler as adapted for forced draught. The middle water-chamber was dispensed with, leaving simply three horizontal cylinders united by tubes—two lower ones containing water and one upper one serving as the steam-exhauster. One of the greatest difficulties to combat with in tubulous boilers was the pitting and corroding action which took place. Its importance could not be over-estimated when it was borne in mind that the Author referred to the thickness of tubes in his boiler as being No. 15 B. W. G., which was slightly thicker than $\frac{1}{16}$ inch; hence it was evident that a very little pitting would render the tube too weak to withstand the working-pressure of 200 lbs. per square inch. There would be considerable risk in the Thornycroft boiler from rapid corrosive action taking place in the tubes, both at the water-level and above it; because, when stopping after a run, that portion of the tube would not be filled with water, although it would be surrounded by the heated products of combustion on their way to the funnel. When marine boilers were out of use it was frequently the custom to fill them with water, to prevent the corrosive action of moist air. If the water-tube boiler were filled with water, it would seem that there would be no possibility of driving out the air from the upper part of the bends. He thought that, in the design of any tubulous boiler, or in fact any boiler, all places for lodgment of air should be carefully avoided; and he

Mr. Yarrow.

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[1] Transactions of the Institution of Engineers and Shipbuilders in Scotland, vol. xxiii. p. 82.

Mr. Yarrow. believed he was correct in saying that the experience of the British Admiralty showed that the worst cases of pitting had always occurred where the plate had been in contact with air. Another cause to which he attributed pitting was the want of uniformity in the material of which the tube was made. For example, in any lap-welded tube a certain amount of scale was almost sure to find its way between the joint at the weld, setting up chemical action. The usual precaution was to fit zinc blocks in different parts of the boilers: he proposed to carry that principle out to a greater extent by adopting tubes of steel galvanized on the inside, which it was hoped would greatly add to their durability. He of course referred to steel or iron tubes. Perhaps the Author would kindly say if he had any extended experience of tubes of copper or brass. He wished to ask what means had been adopted for cleaning the inside of the tubes, because he took it for granted that this was essential. There was always on board ship the possibility of salt water coming over into the boiler. A surface-condenser was composed of hundreds of tubes, each tube provided with a stuffing-box at both ends, and should any of them fail to be tight, the circulating water would find its way into the interior. As a matter of fact, that frequently took place. Again, the grease from internal lubrication from the main engines and the auxiliary engines passed through into the condenser and on to the boiler, and formed a deposit on the heating-surfaces which possessed great non-conducting powers. That, he thought, was almost to be more feared than the collection of salt. In some engines no internal lubrication was provided for; nevertheless, a certain amount of oil always found its way by the piston-rod and slide-valve-rod glands. He considered it essential to provide a ready means for cleaning out the tubes. He expected, owing to the nearly horizontal direction of the tubes immediately over the fire, deposit would collect there in time, and as that was where the tubes were subject to the most intense heat, that they would rapidly deteriorate there. He wished to ask how the Author replaced any of the tubes, because it would seem to be a very difficult operation, owing to their peculiar curved form. No doubt there was some simple mode of doing that; but a boiler, to be successful in practice, must be an easily reparable one. Referring to the design, the Author had stated that the evil effect of unequal expansion had been provided for by a curved form of tube. It might be a question whether this curved form was necessary, because it involved difficulties in the way of internal accessibility for cleaning and facility for renewal. In all recognized boilers, such as the

locomotive type, or the ordinary marine type, the tubes were straight. They were no doubt subject to great variation of temperature. One tube would be filled with cinder and blocked up, precluding thereby any heat passing through it, whereas the adjoining tube might allow the products of combustion to pass freely. In such a case, the two tubes were subject to great variations of internal heating. Again, in one portion of the boiler, the tubes would be enveloped in bubbles of steam trying to rise to the surface, and in another portion of the boiler the tubes would be kept cool by a rush of water from the top on its way to the bottom. He had carefully watched the effect of these variations of temperature, and had never experienced any practical difficulty from them in boilers of the locomotive type worked very hard. Whether the tubes bent, or whether they contracted or expanded to suit these fluctuations of temperature, he did not know; but they caused no practical difficulty. The question, therefore, might be asked whether for tubulous boilers there was any necessity for curving the tubes; because if straight tubes were applicable they offered great facility in construction and for cleaning and repairing. He was of opinion that straight tubes would answer in practice. In making that statement he was not without facts; his firm had constructed several tubulous boilers with straight tubes, which had been worked very hard, and had given no trouble. In their latest, with triple-expansion engines, indicating 260 HP., the weight of boiler was 2 tons 10 cwt., which included water and fittings, giving over 100 HP. to the ton, which he considered a good result. For these reasons he contended that the Author, in bending the tubes to the form shown, had adopted a complicated design, difficult to clean, and difficult to repair, for the sake of providing against a contingency which in practice did not occur. Mr. Yarrow.

Mr. W. B. Bryan stated that he had put up four water-tube boilers to supply a triple-expansion engine with steam for the East London Water-Works Company. Those boilers, although answering admirably in some respects the purposes for which they were intended, were not, so far, quite as economical as the ordinary Cornish or Lancashire boiler. They were safe, and had certain advantages. They worked at about 140 lbs. pressure per square inch. Slow combustion was more economical than quick combustion; in fact, not only had that been found for a great many years past with the ordinary Cornish or Lancashire boiler, but experiments with the Babcock and Wilcox boiler proved this, and he was glad to find that Professor Kennedy's experiments confirmed Mr. Bryan.

Mr. Bryan. the trials that he had himself made on several occasions. He thought the loss of economy in water-tube boilers for land purposes was due, perhaps, to the very large radiating surface of the brickwork enclosing the boilers. For this reason, in boilers used intermittently, as those of the East London Water-Works were at present, the cooling down during the night caused far more loss than the cooling down of the ordinary Lancashire or Cornish boiler. The engines supplied by these water-tube boilers were using, including jackets, slightly more than 13 lbs. of steam per indicated HP. per hour. The boilers were not forced; no water went over with the steam; in fact, the steam was so dry that in a separator put up to intercept any water before going to the high-pressure cylinder, very little water was found after a whole day's working. With regard to grease in the tubes, two of the boilers had been taken off that day, after three months' continuous working, and scarcely any had collected inside the tubes. The high-pressure cylinder was lubricated in the usual manner by a sight-feed lubricator, and the amount of oil used was very small. The engines had surface-condensers. Before the feed-water was pumped it passed through a coke filter, so as to strain away any particles of grease that might have collected therein. The small amount of additional water, required to make up the losses through the glands, was hard water from the chalk, and did not appear to have caused any sediment to collect, because of its very minute proportion to the amount of water returned to the boiler from the condensed steam. There were four boilers, and each had a grate surface of 23 square feet and a heating-surface of 1,070 square feet.

Mr. Woods. Mr. Edward Woods, Past President, remarked that the Author had given a very satisfactory illustration of the application of the principle which he had expounded in the Paper as affecting the circulation of steam and water through tubes in a steam-boiler. It would appear, from Professor Kennedy's experiments, that the economy of fuel in those boilers was at its maximum when the pressure of air in the stoke-hold was equal to from $\frac{1}{4}$ to $\frac{1}{2}$ inch of water, and that the duty done decreased considerably as the pressure in the stoke-hold increased. The experiments, as presented in Table I, showed in one case the air-pressure in the stoke-hold as 0·27, or $\frac{1}{4}$ inch; and the duty done as 10·48 lbs. of water to 1 lb. of coal; whereas, when the air-pressure in the stoke-hold was increased to 2 inches, the duty was diminished to 8·89 lbs. The last-named duty nearly approached that of a locomotive engine, which might be stated in round numbers—not experimentally but in practice—as 8 lbs. of water evaporated to 1 lb. of fuel. He

thought therefore it was tolerably clearly shown by the experiment that the less the draught was forced, by so much was the evaporating power of the fuel increased. He did not quite understand what the zinc plates in the upper member of the boiler were intended for, or what function they performed. He at first thought that it might be to produce galvanic action which would tend to diminish the pitting, the oxidation of the iron in the boiler. Some little time ago his attention was called to the subject of the serious oxidation of the stays and rivets in the boiler of a locomotive where the water used contained sodium-chloride and magnesium-chloride in solution. During his investigations into the cause of it he came into communication with Mr. List, the Engineer of the Donald Currie line, and learned from him that he had applied most successfully to the boats of that company a small galvanic battery—a pile of slabs each ½ inch thick of pure rolled zinc, which was placed in a small chamber, like a mud chamber, below the boiler, the plates being connected with the shell of the boiler by copper conducting wires. The oxidation then took place in the zinc plates which gradually corroded, became decomposed, and could be easily got rid of by removing the man-hole door of the chamber. Since the introduction of that system, the rapid oxidation which had been previously going on in the interior of those boilers had ceased. Mr. Woods.

Mr. J. G. MAIR-RUMLEY said that the question of putting boilers into torpedo-boats was one well worthy of the attention of the Institution, and he thought the Author had solved the problem which all had been anxious to solve—how to get a large amount of heating-surface into a small compass, and a very light boiler compared with its efficiency. The Thornycroft boiler, he thought, had every prospect of being an exceedingly successful one. The only point in it of which he wished to speak was the difficulty, in case of the tubes being split or burst, of their being plugged at sea. A small torpedo-boat in a gale of wind would stand a poor chance if one of the centre tubes had to be plugged. No doubt some simple arrangement could be provided or perhaps the Author, making the tubes of brass, or of some composition of brass, would have the joints so perfect that they would not be liable to split from pressure, or to be affected by heating and cooling action, or by being burnt through grease being deposited inside. In a similar Paper read before the Institution of Naval Architects, the Author stated[1] that the boiler evaporated without forced combustion 13·4 Mr. Mair-Rumley.

[1] Transactions of the Institution of Naval Architects, vol. xxx. p. 276.

Mr. Mair-Rumley. lbs. of water per lb. of coal, from and at 212°. No details were given, but now the records of the trials which were made by Professor Kennedy appeared in the Appendix, and the results showed that the boiler was an exceedingly economical one. The evaporation on the D trial, however, seemed abnormally high. With a Cornish boiler Professor Unwin and he had, on a similar trial, but of twenty-four hours' duration, not been able to obtain such a high result. In the trial described in the Paper, the amount of coal burned was 7·74 lbs. per square foot of grate, while he only burned 7·24 lbs. The amount of air passed through in the D trial was 18·14 lbs. per lb. of coal; but in the other trial it was 16·42 lbs. The temperature of the back flue was 421° in Professor Kennedy's trial, and in the other trial just referred to it was 422°. He was only able to get an efficiency of 77 per cent., whereas the efficiency given by Professor Kennedy and the Author was 86·8 per cent. The question then arose, how did they get a greater amount of heat absorbed by the boilers, the temperature of the back flue being practically the same in both cases? Now it was far easier to get a good result on a five hours' run than it was on a twenty-four hours' trial; and he believed that if the trial had been continued for twenty-four hours, and the boiler and fire had been in the same condition at the end as at the commencement, the result might have been different. As much as 80 per cent. had been obtained by Mr. Longridge, but 86·8 per cent. was certainly without precedent. In producing a boiler with a large amount of heating-surface, a light weight, and occupying a small space, and at the same time very economical, the Author had rendered a service, not only to engineers, but to the English nation.

Professor Unwin. Professor W. C. Unwin observed that the Author had taken a new departure in making boilers of the type under discussion. He had aimed at making a practically indestructible boiler. It would be difficult to repair no doubt, but that mattered very little if the boiler was indestructible. All its parts were of such sizes that they might have excessive strength for their work in resisting the steam-pressure within them. The Author had taken great care —and rightly, for he could not succeed without it—that there should not come upon the parts of the boiler stresses due to unequal heating. The bending of the tubes secured the boiler from any straining action of a kind that could not be allowed for by ordinary calculations. He thought there was every chance, especially if the boiler was of some strong alloy, of making it for all practical purposes indestructible. In the next place, there could be no doubt that the Author for the first time had seen the real

Professor Unwin.

function of an action going on in boilers which had hitherto been neglected. In ordinary boilers, where the rate of evaporation was comparatively slow, there was no very great variation of the density of the mixture of steam and water; but in a boiler pressed into the smallest compass, and using a forced draught to burn 60 or 70 lbs. of coal per square foot of grate, the conditions were so changed, that it was no longer possible to neglect that variation. By turning that to account he thought the Author had almost entirely solved the problem, of having a boiler with enormously powerful combustion and yet uninjured by it. Professor Kennedy had made a point of the boiler working under a wide range of evaporation. Surely that was purely a function of the forced draught. Any boiler, if it would stand a variation of draught such as was used in those trials, would evaporate a correspondingly different quantity of water. He thought that the boiler, from its small mass, would adjust itself to the different conditions of work with great rapidity, and be almost absolutely under control. The Author was to be greatly congratulated on having produced, perhaps, the first boiler which seemed to be really adapted to the conditions of an extremely forced draught, when made of sizes beyond the ordinary locomotive size. Of course a locomotive was a boiler which worked under a forced draught and worked very well, but when pushed to much larger sizes it was no longer satisfactory. The boiler, on the Author's plan, for large sizes would be altogether superior to any type of locomotive boiler. The principal point in the Paper for those who were not practical engineers, but who were interested in experiments with engines, was the series of trials made on the boiler; and in regard to those, he was sure that it would have been impossible for more care to have been taken in their management. Everything had been measured in the most careful way, and he had no doubt that the results as stated were perfectly accurate. But he wished to utter a protest against bringing forward short trials of that kind, and speaking of them in the way in which Professor Kennedy had spoken. When a trial was put forward as a "record," it would naturally be criticised rather more closely than an ordinary trial, which gave results similar to those obtained by other people. The weak point of the trials in question was, that they were boiler trials lasting only a short time, and he thought Professor Kennedy had scarcely realized how much that affected the trustworthiness of the results. Putting out of sight the trial which lasted only two hours, he would take trial D, which was rather a critical one, because it corresponded most

Professor Unwin.

with the trials of ordinary land boilers. The weight of coal, measured out on the stoke-hold floor and put into the furnace, was 1,006·5 lbs., and it was taken to be the consumption of the boiler in the five hours. Obviously, that involved a considerable assumption. The trial began with the fire in active combustion, and ended with the fire in active combustion, and, in order to be sure that only 1,006·5 lbs. of coal had been used, it ought to be certain that the fire was in exactly the same condition at the beginning and at the end of the trial. He supposed that, with the 26 square feet of grate, there would be at least 250 lbs. of coal on the grate in the normal condition of working; therefore, a complication was introduced by the 1,006·5 lbs. of coal having mixed up with it, at the beginning and the end of the trial, a quantity of 250 lbs., or 20 per cent. which had been absolutely guessed—not measured at all. In one respect Professor Kennedy's trial differed from any that he had known. During the last hour the whole of the ashes had been put back on the fire. It appeared, from the analysis of the coal, that there must have been produced out of the 1,006·5 lbs., 22 lbs. of incombustible ash. There was, therefore, in the fire at the end of the trial an amount of 22 lbs. of incombustible ash which was absent at the beginning, and as the fire could only be judged by its bulk, he thought Professor Kennedy, even on his own mode of estimation, ought to have added 22 lbs. to the 1,006·5 lbs., as the coal burnt on the trial. That was, a quantity of 22 lbs. of incombustible matter was on the grate at the end of the trial, which replaced 22 lbs. of combustible on the grate at the beginning. It might be said that 22 lbs. was a small quantity, yet it was 2 per cent. of the whole amount burnt. But he ventured to say more than that; Professor Kennedy understood well that the weak point of the trial was the judging of the fire at the beginning and at the end, and he had made a remark about it, stating that in the diagram of coal consumption during the trial, the straightness of the line would form a criterion whether the fire was in the same condition at the beginning and at the end of the trial. It would be seen from the diagrams that towards the end of the trial less coal was put on the fire. The line was made tolerably straight by adding the weight of ashes, containing only 85 per cent. of carbon, and treating it as if it were good coal. To some extent that was right; but if the diagram were appealed to, the fair inference from it would be that the fire was let down at the end and was not in the same condition at the end as it was at the beginning. As the fire could only be judged by bulk, and the bulk was a bad criterion of the weight (for the coal might burn half

way without showing much difference in the bulk), he thought an error of at least another 42 lbs. might have been made. The possibility was, therefore, that there was another error of 4 per cent. in the judgment of the fire. On the whole, allowing 2 per cent. for the ashes put back, and another 4 or 5 per cent. for the probable difference of the fire, it was quite possible, the trial lasting only five hours, though made with the greatest care, might be out by 10 per cent. Of course, in the case of a torpedo-boat, a longer trial might be impossible; but in a trial of that sort it would be well to put forward a little more prominently the fact that from its shortness there was a likelihood, when so high a figure was reached, of there being some error in it. Professor Kennedy might say that he had a correct balance-sheet; but unfortunately the balance-sheet for trial D was rather too good to be true. A large amount of the heat measured was given to the steam; and a large amount to the chimney, and, throwing away the mere bagatelle wasted in carbonic oxide, there remained only 1·9 per cent. of heat to account for, which Professor Kennedy had put down as lost by radiation. He did not know any trial in which the loss by radiation was so small as that; such a figure was more remarkable than the 13·4. The trials themselves seemed to show that it was an impossible value, which ought to have raised a little suspicion. The loss of heat by radiation from a boiler of that kind, in which the outside surface was at much the same temperature, whether the consumption was 7 lbs. of coal per square foot of grate or 40 or 50 lbs., was constant. Every experiment made to determine the radiation loss assumed that it was a tolerably constant quantity of heat. But in that case the percentage of the loss by radiation must diminish as the consumption of coal was greater. If the quantity of coal burnt on the grate was doubled, the percentage of loss would be halved. He would not take one of the extreme trials, but the trial nearest to D, namely trial C, which lasted the same length of time. The chief difference was that the coal burnt was two and a-half times as much per square foot of grate. In trial D the loss by radiation was put down at 1·9 per cent.; in trial C it was 3·6 per cent. If the radiation loss were constant, working from trial C backwards, the loss by radiation in trial D should have been about 10 per cent., or two and a-half times 3·6 per cent. At any rate the discrepancy was so great that it ought to have raised a suspicion that the balance-sheet for trial D was a little too good to be true. Professor Unwin.

Mr. JOHN FREDERICK SPENCER said that at the close of his apprenticeship he was associated with Mr. L. E. Fletcher in working his steam-carriage, under a steam-pressure of 360 to 500 Mr. Spencer.

Mr. Spencer. lbs., in a barrel tubular boiler. The safety-valve was set at 360 lbs., but as they had to screw the spring-balance down when they came to newly-made road, they estimated that it increased to nearly 500 lbs. per square inch in the interval. This showed that very high pressure was not a new experience. The only object in that case was to reduce the weight, economy was not thought of; in fact, it was in the days when even the link-motion was not established, and when the only gear for reversing was gab-gear; but it was interesting, as showing that very high-pressure steam was used then in an ordinary tubular boiler with a fair amount of safety. When Mr. Flannery's Paper on the construction of steam-boilers was read, he was about placing four Perkins' boilers in a large steam yacht, but they unfortunately proved a failure. The cause was very simple. It was one of those failures which often arose from slight mechanical defects. The upper part of the boiler was connected with the lower part by copper rings, and the limited amount of water having to be constantly supplied, some little deficiency occurred at sea; the junction of the boiler became overheated, the copper rings were pressed in, and when the boiler cooled again there was a constant leakage. He had great faith in the Perkins' boiler, and he could never think or speak of Mr. Perkins without the greatest respect, for he believed no man had worked harder or more conscientiously to raise the pressure of steam for the purposes of economy, and improvement in engineering. There was, however, the fact that a strong boiler that would have stood safely 2,000 lbs. pressure per square inch, failed in consequence of a small mechanical detail. He confessed he felt much safer in the yacht when the boiler was under a continuous pressure of 400 or 500 lbs. for seventy-two hours, in going to Ailsa Craig, than he did on Lake Champlain, when his bunk was over a boiler 10 feet in diameter, of $\frac{1}{4}$-inch plate, and with single-riveted joints working at 40 lbs. per square inch, the strain on the metal section being nearly 10,000 lbs., and on the joints more than 16,000 lbs. Circulation in the Perkins' boiler was non-existent, and yet the steam was comparatively dry. If the mechanical defect to which he had alluded had not occurred, he believed that the yacht would have continued to the present time with the Perkins's boiler in it. In 1859 he designed two pairs of boilers for two Atlantic steamers with water-tubes, a plan common in America at that time, and he believed that some of them were still in existence. He went to America in one of those ships, and great trouble was experienced from deficient circulation, so that the boiler could scarcely ever be kept from priming. Messrs.

Lumsden, of Hull, had some of these boilers in the paddle steamship "Lion," but they could only work them efficiently by allowing a few inches of water over the upper tube-plate. With water nearly down to this plate the boilers gave dry steam, which seemed to corroborate the Author's experience with reference to the evil of their discharging water and steam into the water-space above, with no chance of separation. In his remarks on Mr. Flannery's Paper he had stated, what he now repeated, that it was an anomaly in steam-engineering that safety increased with increased pressure. There could be no question about it. It had been shown in many ways. The Board of Trade Regulations had greatly resulted from increased pressure. With low-pressure steam accidents were much more frequent, because the boiler construction was neglected, very little care was bestowed on its design by scientific engineers, and the riveting and staying had little attention paid them. With high-pressure steam the square had to give way to the circular form, and it was found that as much attention had to be devoted to the manufacture of the boiler as to the machinery; in fact, the boiler, as a question of safety, required greater care than the engine in its manufacture. The size of the furnace of the water-tube boiler described was a most important point, as in a large area, 6 feet by 5 feet, he considered it almost impossible to keep up good stoking regularly. It might be done with a special set of expert stokers; but in the general run of the mercantile marine the larger the fires the more difficult it was to get an equal quality of stoking. If he understood the design of the boiler, when the height of large steamships was utilized, larger areas of fire would be required, and then machine-stoking would become of great importance. With reference to the closed stoke-hold, the original idea, as it first appeared in print, emanated from Mr. L. E. Fletcher, of Manchester, several years prior to 1855. This fact did not at all detract from the originality of the Author's design, but it was fair that it should be mentioned. In a patent which Mr. Fletcher had taken out, he included closed stoke-holds for forced combustion. With reference to the trials for evaporation, his experience did not warrant a belief in any that lasted only five hours; much longer trials were required, the difficulty of obtaining reliable working results in so short a time being very great. He did not doubt any facts given in the Paper, which he considered one of the best that had been presented to the Institution on the subject of steam-boilers. Whether the precise form or arrangement included in the Thornycroft's boiler would bear the test of a lengthened experience or not—and there were many Mr. Spencer.

Mr. Spencer. reasons why it should do so—the Paper might be accepted as an important contribution to progressive boiler design for high pressure. Without active and persistent circulation, all boilers working with impure water became inefficient and non-conductive through internal deposit; and it would be impossible in small tubing to provide for the removal of such deposit by mechanical means, as could be done with the Howard, Root, or Babcock water-tube boilers. It was therefore of the first importance that circulation should be active and continuous in a boiler such as the one described in the Paper; and this led to the most distinctive feature of the design, the free discharge, without obstruction, of mixed steam and water into a separator, thus ensuring a free muzzle for such discharge, and the certainty of having no portions of the small tubes, containing steam only, exposed to heat or flame, experience having proved the destructive effects of flame on tubes in a heated flue when filled with steam only. The boiler also was independent of brick or water-space surroundings, and the continuous wall of tubing was a distinct improvement, as even with the Perkins' boiler there was great difficulty in charging the charcoal casing, and great heat passed through owing to the defective non-conductive casings. Reduced weight and occupied space, maximum steam-pressure, greater portability, and increased safety would all be included in the change from tubular to tubulous boilers, if past failures in design could be avoided, and his own experience confirmed very largely the belief, that the Author had succeeded in such avoidance. The furnace was an important part of a boiler, and, in the present Lancashire and marine type, was much more confined in space over the grate than was desirable for efficient combustion and mixture of the gases. Here again the Thornycroft boiler seemed all that could be desired, giving a large combustion chamber, the evaporative duty per lb. of coal mentioned in the Paper being at least 30 to 40 per cent. in excess of that realized in the present marine boiler. It would probably be found possible to vary considerably the proportions and arrangements of the Thornycroft boiler, to suit varying circumstances, without departing from its leading improvements, including a scouring circulation and large heating-surface.

Mr. Crohn. Mr. F. W. Crohn said that the first example of forced draught by a closed stoke-hold, with which he was acquainted, was that of the celebrated cigar-shaped steamer "Ross Winans," built in 1864–5 by Messrs. Winans at Poplar. The stoke-hold could be closed by air-tight doors, and air could be forced into it by a fan,

from 4 to 5 feet in diameter, driven by a donkey-engine and belting up to 800 revolutions per minute. Air-pressures up to 9 inches of water were used, and the quantity of coal burnt per square foot of grate sometimes exceeded 1 cwt. per hour, an amount seldom if ever exceeded, even at the present day. Mr. Crohn.

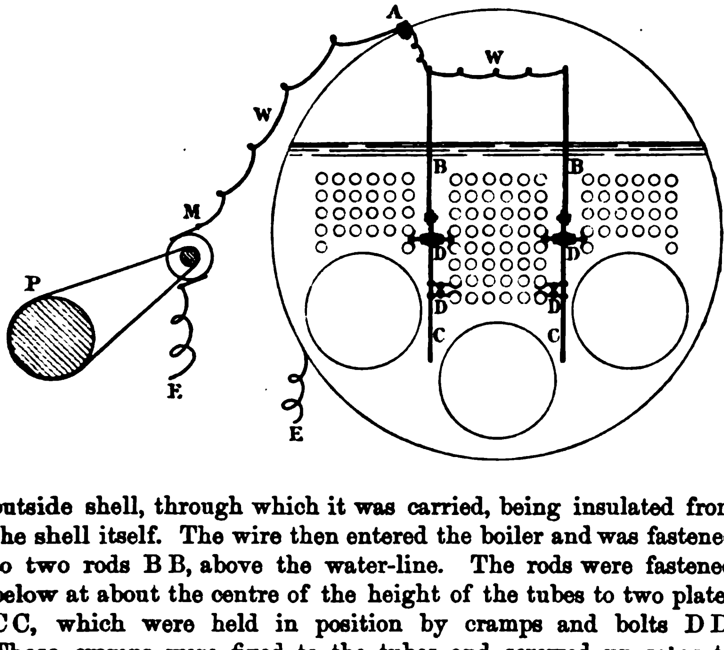
Mr. E. A. Cowper observed that Professor Unwin had spoken of 23 lbs. of ash, but the amount stated was 233·5 lbs. as "put back on fire." He regretted that he had not seen the boiler at work. At first sight he was inclined to ask the question whether the tubes were likely to get burnt or over-heated or furred. That, perhaps, was partly because he felt prejudiced against having water in small tubes, owing to the numerous failures of tubular boilers of different constructions, with tubes even, he believed, as much as 8 or 10 inches in diameter. But there were tubular boilers in the country with tubes 5 inches in diameter that had not always worked satisfactorily. Of course, with stationary engines boilers must work steadily and quietly, not giving so much trouble as to require attention every two or three minutes. There was plenty of room in Cornish boilers with Galloway tubes, but in a steamboat the conditions were different. There it was wanted to get as much steam from every square foot of surface as possible, and it was admissible to require that stokers should pay more attention to the boiler and look after the water-line more frequently than in a stationary boiler. It was therefore possible to make a boiler with much less water in it, or, as he called it, a much smaller "pond" of water. If the pond was large and deep it could be allowed to remain some time without attention, because the quantity of water to be evaporated before the tubes became dry was considerable. If the pond was small, and the tubes were only a small distance below the surface, it could not be left for any length of time. Given the condition that any amount of attention might be paid to a marine boiler, especially in a torpedo-boat, it was possible to have tubular boilers of such construction as not to get burnt, and not to get choked by sediment. He believed the Author had made such a boiler, and if it was successful it was greatly owing to the powerful circulation set up in the tubes. The difference of the weight of the ascending column of steam and water, and the descending column of water only, was considerable. If the boiler was only made a foot or two in height, it would not work so well or so safely, because the circulation would be slower, and the propelling power through the tubes would be less. With regard to the circulation, the Author had exhibited a diagram illustrative of the movements of the struggling currents of the Mr. Cowper.

Mr. Cowper. steam and of the water. Mr. Cowper's father had told him when a boy, that Mr. Jacob Perkins was arranging a boiler so that the water going up with the steam should ascend in one direction, and the water coming down without the steam should descend in another direction. He then got a garden pot, knocked the bottom out of it, and put it in a saucepan, and it was impossible to make the water in the saucepan boil over because the circulation enabled the steam to escape freely. But when the circulating cylinder was taken out it boiled over directly. The Field tube owed its life entirely to such a circulation. No doubt good circulation in a boiler was the salvation of the plates, because the water carried away the heat fast enough to keep down their temperature. By way of illustration from an extreme fact, he might say that the waste heat from a puddling furnace, if allowed to play against the vertical plate of a boiler, having many feet depth of water on the other side, would certainly ruin it; to save the boiler it would be necessary to put a protection of brickwork against the plate, and let the heat pass round the boiler. But take another case, it was possible to work a tuyere thrust more than a foot into a blast-furnace, with a current of air through it at 1,500° Fahrenheit, by passing a stream of cold water through a coil in the metal of the tuyere, the water coming out warm but with no steam. In this case the cold water would control the temperature of the metal, but in the previous case the products of combustion would control the metal. The water-tube boiler under discussion was very different in construction from those that had gone before, and, from possessing a very powerful circulation, no doubt its life would be much longer. The experiments of the Author and Professor Kennedy were extremely interesting and satisfactory, and he hoped they would lead to the construction of powerful boilers of the same type, so as to avoid the necessity of having large cylindrical vessels with a very heavy pressure in them. In case of a collision, if a vessel ran into a boiler and gave it a nip, the boiler would explode and probably open out the side of the ship, as, he believed, happened in the case of a ship going to Antwerp, which had been cut in half. He congratulated the Author on having gone so far towards making a tubular boiler, much less in weight than any ordinary boiler with a large body of water, much safer, and capable of carrying any pressure in reason.

Mr. Dolby. Mr. E. R. Dolby said that Mr. Woods had alluded to a method of using primary batteries to pass electric currents through boilers to get rid of incrustation. He might be permitted to mention a method which had some advantages over that. The disadvantages in the use

of galvanic batteries were that it was extremely difficult to keep up a continuous current for any length of time; that the zincs rapidly wore out, and that in hot climates the solution required continual attention. The system to which he was alluding was shown diagrammatically by *Fig. 3*, which represented a marine boiler in section fitted up. The apparatus itself was shown by thick lines, the rest of the boiler by lighter lines. P was the propeller shaft. A small dynamo or magneto-electric machine, marked M, was driven by a strap from the propeller shaft. The outer circle represented the commutator. Two brushes were shown, and from the top brush was led a wire W, which went to a point A in the Mr. Dolby.

Fig. 3.



outside shell, through which it was carried, being insulated from the shell itself. The wire then entered the boiler and was fastened to two rods B B, above the water-line. The rods were fastened below at about the centre of the height of the tubes to two plates C C, which were held in position by cramps and bolts D D. These cramps were fixed to the tubes and screwed up so as to wedge the plates in position, but they were insulated from the plates themselves. The small magneto was an alternating machine, and the current, supposing the top brush to be at first positive, would pass by the wire outside, enter the boiler, and from the two electrodes C C would pass through the water to the shell, from the shell by the short wire to earth and back again to the other brush. When the next alternation came the current would pass

Mr. Dolby. by earth to the shell, and from the shell through the water to the plates. He believed the effect of the alternation would be that as the current passed through the water it would electrolize a small part; the hydrogen, acting as a metal, would follow the course of the current, and would be, by his first supposition, deposited upon the shell and flue tubes. When the current changed, oxygen would be produced on the same surface. The two would combine and form a thin film of chemically pure water, which would hinder the deposit upon the shell; also the throbbing caused by the alternations of current would loosen any scale already adhering. He exhibited a small magneto machine with some samples of the scale, and of the insulating portion A. He might mention that the strap was not put direct from the shaft on to the small machine, as it needed to go at a much higher velocity; also that the wire shown to the letters E E, was not necessary, as one of the brushes was in electrical contact with the frame, and the machine was usually put on a metal bracket, in connection with the hull of the vessel, and as of course the boiler was in connection with the hull, only one wire was needed. The apparatus was covered by several patents worked by the Alterion Company. The insulator through the shell was of woodite, and there were two washers of asbestos drawn together by nuts. Of course the system was also applicable to land boilers. The insulators inside might be of porcelain.

Admiral Selwyn. Admiral J. H. Selwyn was delighted to find the Author a strong advocate of the tubulous boiler. He did not think it was quite fair to attribute so little to the Perkins boilers, which had been at work since 1831, and he believed that one of them was now in use in the City of London. Two of the boilers belonging to the "Wanderer" were still in existence; no difficulty was experienced with them, and the owner would not change them for any other boilers that he had seen. They were perfectly good, and ready to take 500 lbs. pressure per square inch, or even more, though one had been working for seven years. The previous boiler in the same establishment was made for Messrs. Spratt, in 1839; it was re-erected in 1842, and had been in use ever since. Remembering the men who had made steam at high pressure their hobby, from Jacob Perkins, 1819 to 1836, A. M. Perkins from 1831 to 1860, and Loftus Perkins from 1859 to 1883, an enormous amount of knowledge must be comprised in their published works. It was well known that the copper-packing ring was made in 1871, also the metallic packing which had given such great satisfaction, leading to the exclusion of lubrication in the cylinder, and the avoidance of that fatal defect in boilers which had so often been

lamented in rivers in America, where a skin of oil had got over the water and had led to fatal explosions. The Field-tube boiler was simply a repetition of Jacob Perkins's; the tubes were made originally under the Perkins' patent in 1831, only slightly changed into the trumpet mouth from the conical mouth. There was scarcely one tubulous boiler that had not been more or less anticipated by the Perkins' patents. The work of those men was worth studying. Their patents had long since expired, and it would be wise to take up all the information contained in them. By high pressures only could true economy be obtained with steam. The other principal economies must come from heated feed-water and heated air-supply. But the greatest would be in the coming fuel, which would be liquid and gaseous, the latter largely derived without increased cost from the air. When boilers in the Navy were subjected to about 10 lbs. pressure per square inch people were afraid of them. With every increase in pressure there had been a less quantity of coal burned to produce 1 HP., from 9 lbs. in 1830 to 1·5 lb. in 1886. No doubt there would come a point (perhaps 500 lbs. was near the mark) where the economy would not be so great. Considering what the pressures already were, when the proposition was made to construct a boiler with tubes of double curvature, whose ends were inserted into comparatively large pipes, and were only retained by ferrules and ordinary expansion, it might be asked whether there was not a serious risk of racking or straining the expansion-joint in the hole into which it fitted, and of the joint eventually failing to support the pressure. As pressures increased, no doubt the danger of explosion was lessened. Moreover, the quantity of water was so small that if a shot was driven through the boiler, the steam would not scald anybody. Some years ago he put his hand into steam coming direct from the boiler at 300 to 350 lbs. pressure per square inch, and it felt quite cold; and it was well known that steam close to a safety-valve, issuing at 50, 60, or 70 lbs. per square inch, would feel cold, but at a little distance it would feel warm, and further off it would be scalding. He agreed that an increase in pressure meant an increase in safety; but had the advance in the factor of safety allowed in boilers increased in proportion to the pressure? He feared not. He was afraid that if he asked any engineer to put on 2,000 lbs. pressure per square inch in testing a boiler for 500 lbs. working pressure, he should only be regarded as mad; but this was what Mr. Perkins had always done, and he believed that engineers would bear him out in saying that the true factor of safety was four times the working load. He Admiral Selwyn.

Admiral Selwyn. wished to know whether the statement that had been made by Rankine, that the conversion of coal into gas absorbed 2 or probably 3 units of heat out of the total calorific effect obtainable from coal, was true or not; because, if that were added to the 2 units of heat which went up the chimney at a temperature of 600°, after deduction of incombustible ash besides the radiation, which his experiments had shown with a well-lagged 40 nominal HP. marine boiler using oil was equal to about one-tenth of the total fuel employed, whence came the high evaporation, and what was the quality of the coal that produced it? Pure carbon only gave 15 lbs. evaporative duty. The small quantity of hydrogen in some coal might contribute something more, but it had not done so yet. He viewed the statements as to the enormous evaporative duty of coal with great distrust, particularly as late trials in America had confirmed all that the naval authorities had said, namely, that at sea they could not rely on more than 8 lbs. of water evaporated by 1 lb. of fuel. It was not on trials extending over four or twenty-four hours that reliance should be placed, but on more nearly twenty-four days, because such alone could give trustworthy results. It was an ancient piece of knowledge that by forcing the fire with a pair of bellows more coal indeed could be burned, but not economically. It was inevitable that much more heat would be thrown up the funnel, and a much less effect would be produced economically.

Mr. Stroudley. Mr. W. Stroudley said he thought that the boiler explained in the Paper was one that had been before the public for many years, but the Author had thrown a new light upon it in the matter of circulation. The failure of all water-tube boilers hitherto had, he believed, arisen from internal incrustation or from burning out of the tubes from the want of a proper water-supply. The exigencies of a torpedo-boat were such that they had caused the Author to turn his attention to something different from the locomotive boiler as a steam-producer, and in the boiler exhibited he had adopted a system in which safety was a consideration as well as simplicity of material and construction, and he had at the same time carefully provided for the extreme variations of temperature in the different parts of the boiler. The mode of circulation by the difference in the weight of the two columns was simple enough; the separation of the steam from the water when ejected from the upper ends of the tubes was also a thing with which engineers were familiar. In the blacksmith's tuyere the same arrangement had been in use as long as he could remember, and it worked in precisely the same way; the tuyere and tubes kept clean, and there was no

incrustation or disturbance. The burning out of the old-fashioned tuyere with the upright pipe turning over the top of the cistern, and terminating above the level of the water, was a very rare thing, although the heat to which it was subjected in a large smith's-fire was very intense and local. He thought, therefore, that looking at the boiler as a torpedo-boat boiler, and as a possible marine boiler for large ships, where weight and concentration were of great importance, there was a very reasonable hope for success. The large heating-surface, the low temperature at which the gases could be reduced before they escaped at the funnel, the comparatively large grate which could be provided with a mere change of form of the tubes, afforded advantages which would be generally appreciated by engineers. Beginning on a small scale, it was reasonable to suppose that the boiler would work up to the larger powers required in ocean-going steamers. He thought it was particularly adapted to the differential temperatures that might arise in a boat put into violent motion at full speed under a forced draught, and then immediately closed down, the evaporation being reduced perhaps 99 per cent.—the very cause which destroyed an ordinary locomotive boiler or a boiler of the locomotive form. This boiler had another advantage in possessing the means of being extended to a very large size. He agreed with a previous speaker that the locomotive boiler was not adapted to extremely large sizes; it was not therefore adapted to steamboat work. The Thornycroft boiler had a great many qualities that were clearly advantageous, but he did not see how repairs or renewals of part of the tubes could be easily effected in its present form. Mr. Stroudley.

Mr. W. R. Hodge thought that considering the progress of marine-engine science, and the extreme steam-pressures now obtaining, the old-fashioned boiler might be regarded as doomed, and that eventually some other description of boiler would be necessarily used. The boiler which it seemed safest to adopt was the tubulous boiler, and that had been known for many years. A safer boiler had never been constructed than the Perkins boiler. He should like to think as highly in that respect of the Thornycroft boiler, but at present he was afraid to express an opinion on the subject in the absence of sufficient experience. He was doubtful whether, under certain conditions—water failing and the use of salt water—the tubes would not very soon be stopped, and become inoperative, in fact, be burned out. There could be no doubt that the Author had succeeded in arriving at a high standard of efficiency in the rate of evaporation. Engineers had hitherto looked on about 10 lbs. of water evaporated per lb. of fuel as the Mr. Hodge.

Mr. Hodge. maximum with ordinary boilers. He had known as much as 12½ lbs., but the Author had succeeded in getting a still higher rate in his water-tube boiler. It was a species of vertical boiler, although it was well known that vertical surfaces were less operative and successful in absorbing heat than horizontal surfaces. The marine boiler had a large extent of horizontal surface, and therefore would be ordinarily more efficacious. How the Author obtained the result given was not clear to him. No doubt it had been attained, but neither the Author nor Professor Kennedy had explained how the gases got away; nor did the calorimeter show it in this case. He thought it was by forcing the gases through very restricted areas before reaching the chimney, thus retaining them in the furnace a long while. Under ordinary draught the boiler did not do very much; to get any marked effect there must be forced draught. 7¾ lbs. of coal per square foot of grate was, of course, a low rate of consumption; in ordinary marine boilers it varied from 14 lbs. to 24 lbs., within which the best results were obtained. His own impression was that more effect would be obtained by a combination between the Perkins and the Thornycroft boilers. He did not consider the Thornycroft water-tubes sufficiently large for practical commercial marine purposes. A stride, however, had been made in that direction, and he felt satisfied, if the pressures went on increasing as hitherto, some sort of tubulous boilers would have to be adopted. The other boilers were necessarily doomed, and the sooner engineers addressed themselves to that question the sooner they would arrive at a practical conclusion as to the most desirable kind of boiler.

Mr. Wingfield. Mr. C. Humphrey Wingfield observed that by taking as a base-line for a curve the number of lbs. of coal burnt per hour per foot of grate-surface, and setting up as ordinates from that base-line the number of lbs. of water evaporated per foot of grate-surface, the curve soon became a straight line, showing that each increment of coal burnt per foot of grate-surface produced a corresponding increment of water evaporated. He had taken the figures from the Paper, and had plotted them in that way, and he found as a result that, starting from any point on the trial and taking an increment of 1 lb. of coal per square foot of grate, the Author obtained for that 1 lb. an additional 10 lbs. of water evaporated per foot of grate; and that as many additional lbs. of coal per foot as were burnt would each add 10 lbs. more water evaporated per foot of grate. In the case of a locomotive boiler described before the Institution in 1881, some figures were given which compared with the present, and he found that each additional lb. of coal burnt per foot of grate would

evaporate an additional 5·5 lbs. of water per square foot of grate. So that if, by blast or otherwise, the consumption of coal in the Author's water-tube boiler was increased by 1 lb., 10 lbs. of water would be gained; and if the consumption of coal was increased by 1 lb. in a locomotive boiler, only 5·7 lbs. of water would be gained, or little more than half. Mr. Wingfield.

Mr. F. E. Duckham said he was neither a torpedo-boat builder nor a user of torpedo-boats, but, like other engineers connected with machinery, he was always on the look-out for anything which would improve the efficiency of that under his care. He had therefore read the Paper with much interest, in the hope of finding in it something that he could apply to his own purposes. But apparently even the Author had not yet found the philosopher's stone with reference to steam-boilers. He had accepted the high efficiency said to have been obtained in evaporating 13·4 lbs. of water, but did not approve of the construction of the boiler. It appeared from the illustration that the water-line of the boiler in the upper tube, and consequently in the water-line the pipes themselves, would be somewhat below the top of the bend of the tubes. Those who were connected with machinery instinctively abhorred two things; first, a screeching bearing, and secondly, a boiler where the water-line was below any place within the operation of fire. A considerable portion of the top of the tube in the boiler appeared to him to be the same in relation to the fire as the crown of a firebox would be; so during the getting up of steam, and at any time except when the boiler was in active operation, the upper portion of the tubes was not protected by the influence of the water passing through them on the inner side. The Author stated that curved tubes were adopted to allow for the difference of expansion between those which were more particularly under the influence of heat, and the outer ones, which were not so much under that influence. He thought that if the tubes were straight, instead of curved, although the inner tube might expand perhaps a thousandth part of the length more than the outside one, the lower vessel would simply turn slightly round, taking the outer tube as the point of radiation, and no harm would be done. On the contrary, the boiler would be simpler, it could be more easily repaired, and would be without the objection in relation to the upper part of the tubes getting burnt. Of course, there were advantages connected with water-tube boilers as to fire-grate surface and the like, on which he need not dwell. Another matter, to which reference had been made, was the use of electro agents of some kind for the reduction of the scale. Some time ago he had tried a Mr. Duckham.

Mr. Duckham. coating of coal-tar inside boilers of the Lancashire type, and he had found in the first instance that the scale previously deposited was loosened and removed, and no trouble had been experienced afterwards. Instead of their having to be chipped and cleaned every three weeks, they would go untouched for two or three months without difficulty. As compound engines came more into use, there would not be the same chance of deposit; but, by occasionally coating the boilers inside in the way he had stated, very great advantages were gained without the aid of electric apparatus.

Mr. Willans. Mr. P. W. WILLANS said he thought it was a question whether the separator, to which the Author had referred, did the work of separation perfectly. He had tried many experiments in the way of separating steam in separators, and he was doubtful whether the moisture in the steam could really be withdrawn. Could the Author produce any statistics as to the quality of the steam? He agreed with Professor Unwin that two or three hours was too short a time to try a boiler. Experiments on the boilers on land should be made and should be continued for at least twenty-four hours. The figures of the trials rather seemed to show that when the boiler was forced there was a considerable amount of water in the steam; for he did not see why the forcing of the boiler should affect the efficiency of the engine as an engine, unless the forcing also caused water to come over with the steam from the boiler. The vacuum rather fell off in the last trial, but that was not sufficient to neutralise the gain to be expected from using steam at a pressure of 168 lbs. instead of 120 lbs. per square inch. The figure for water consumption of the engines per indicated HP. was about 20 lbs. After making even a large allowance for the water used by auxiliary engines, that was a great deal for a high-class engine. He supposed it might be taken that 15 lbs. was the result which should be obtained with dry steam; if the steam was wet it would make a great difference. The question simply was this:—Was the Author making steam or steam and water? Careful calorimeter tests could alone determine this.

Mr. Halpin. Mr. DRUITT HALPIN remarked that in trial C, Table I, the equivalent evaporation was given as 12·48 lbs., everything being taken from and at 212°. That was what he called the economy of evaporation. The rate of evaporation, which was a totally different matter, was given as 3·20 lbs. per square foot of heating-surface per hour. He had for a long time looked upon boilers as machine-tools, and he always considered that those figures should be taken in conjunction to get the total efficiency at which a boiler was

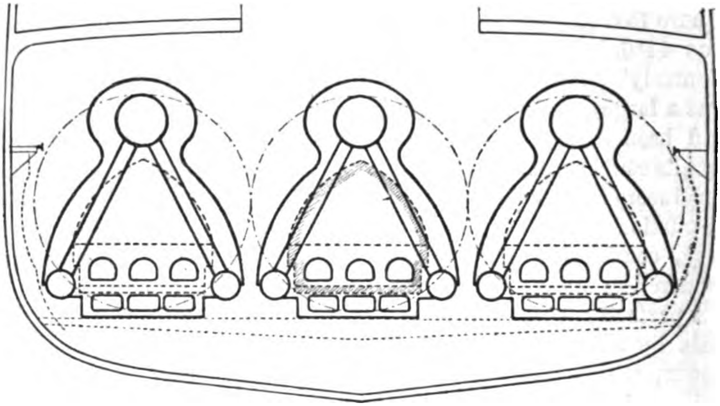
working. Multiplying the figures by each other, a factor of 39·93 was arrived at, which was excellent. On the previous Saturday he had seen an ordinary locomotive boiler tried, having $2\frac{1}{2}$-inch tubes, $\frac{7}{8}$-inch spaces, and no measurable blast in the chimney. The equivalent evaporation in this case was 12·12 lbs., and the rate at which the evaporation took place was 3·68 lbs. of water per square foot of heating-surface per hour, so that the final efficiency was 44·6, being 8 or 9 per cent. above that given by Professor Kennedy's trial. Of course, in such very high figures 8 or 9 per cent. was a large quantity. It was a great pity that the trials described had been carried out under such circumstances that no definite results could be obtained from them. The Institution of Mechanical Engineers had lately had the subject of marine-engine trials under discussion [1] when he stated, what he now repeated, that it was a pity, considering all the expense, a little more had not been incurred in order to carry out the experiments on shore, so as to get perfectly accurate results. Many of the builders had steaming beds by which an engine could be tested up to any reasonable power, which could be absorbed with very little trouble and expense by water brakes. In that way trustworthy results would be obtainable. One anomaly was shown in Table II, where the amount of jacket water was given. In engines well jacketed, the percentage of water appeared to be extremely small, showing that an abnormally large proportion of the steam must have been going through to the auxiliary engines. He was not quite satisfied with the way in which the trials had been conducted. He had stated at the meeting of the Institution of Mechanical Engineers to which he had referred, that the Research Committee was trying—and rightly—to popularize the carrying out of such trials, but he feared it had gone the wrong way to work. The Committee had started with the idea that in carrying out the trials it was necessary to fill the ship with tanks and measuring apparatus, which were cumbrous and difficult to deal with. He thought that the same object might be obtained as certainly by positive meters, of which there were plenty in the market. He was now using positive meters in many boilers, so that all the coal put into the furnace was weighed, and every drop of water evaporated was given credit for; it was thus possible to keep an actual debtor and creditor account. Mr. Halpin.

Mr. JOHN LIST said, with regard to the suitability of the Thornycroft water-tube boiler for ocean steaming, that since the question of its evaporative efficiency had been fully discussed, he did not pro- Mr. List.

[1] Institution of Mechanical Engineers. Proceedings. 1889. p. 235.

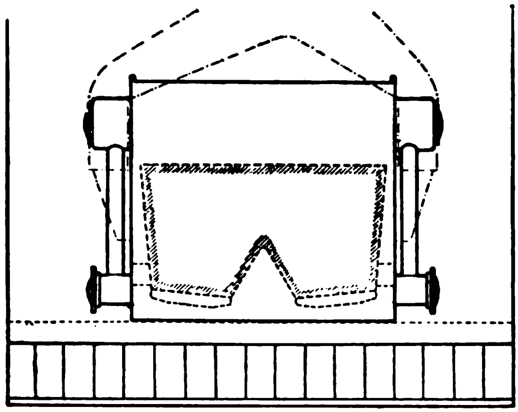
Mr. List. pose to refer to that point further, than to remark that evidently it had a considerably higher efficiency than the ordinary form of high-pressure marine boiler now in general use. Three such boilers were shown in place (*Fig. 4*), in the section of a mail

Fig. 4.



steamer of 48 feet beam. *Fig. 5* was a longitudinal elevation, showing the uptakes and the stoke-holds forward and aft. These boilers, having a working pressure of 160 lbs. per square inch,

Fig. 5.



had each three 40-inch corrugated furnaces at each end, or eighteen in all, with nine middle combustion chambers. The total heating-surface was 11,260 square feet, and the fire-grate

area 360 feet. They were 14 feet 4 inches mean diameter, and 17 feet 9 inches long, and would, with natural draught, give about 4,300 indicated HP. at sea. The total weight of the three, with water, mountings, non-conducting covering, uptakes and funnel, was 356 tons, therefore 12 indicated HP. was developed per ton of weight. Comparing these figures with those which had from time to time been published of the machinery of war-ships, the weight appeared excessive; but it ought to be borne in mind that these were the boilers of a steamer which was driven up to its maximum speed for twenty days continuously, part of the voyage being through the tropics. The type of boiler to which he referred had been successful for pressures up to even 180 lbs. per square inch, and was now regularly adopted at sea with pressures from 15 to 20 lbs. below that. In careful hands the boilers gave no trouble, and were worked continuously for voyages to the Colonies of several months' duration, with practically no up-keep on them except renewing the fire-bars. They were accessible for cleaning, so that any oily deposit could be readily removed from the water-spaces; and, where the waste of water was made up by distillation, practically no scale was deposited. In careless hands, however, such boilers would, and did, give considerable trouble. From what the Author described as the "struggling confused" circulation of the water in them, and from their great length, they were liable to be seriously strained by raising or lowering the steam-pressure too quickly; also by admitting large volumes of cold air to the furnaces and combustion-chambers in cleaning fires, or by pumping in cold feed-water. If care was not taken to avoid irregular expansion and contraction from those causes, leakage at the back tube-plates, the furnace-ends and the lower parts of the circumferential seams of the shell, was almost certain to follow, and was difficult to remedy. From a constructive point of view these boilers were costly to make, as they involved the use of heavy plates, and valuable plant to work the plates into form. When made, they were difficult to handle on account of their size and weight, requiring powerful sheer-legs to lift them into the ship; and, in the event of being damaged when in use, they were difficult to repair in place. The Thornycroft boilers were of an essentially different type; they depended entirely upon circulation. Having made a short trip in a torpedo-boat fitted with them, he wished to say that undoubtedly the circulation was excellent. They consisted of a large number of small parts, each part having a large factor of safety; and it appeared to be a form of boiler which could not readily be made Mr. List.

Mr. List. to leak, even when exposed to the most severe treatment. That the parts composing the boiler could be put together *in sitû* on board ship was a strong recommendation in its favour, as when such boilers were worn out they could be replaced without involving the lifting of decks, casings, &c. Remarks had been made as to the difficulty of plugging the ends, in the event of one of the tubes failing; but probably in larger boilers of this type the receivers would be of such a size as to give ready access to the insides of the tube-plates, and certainly they could be blown out at sea, cooled down and refilled with water, in less time than a boiler of the ordinary type. The curved form of the tubes appeared admirably adapted to allow for unequal expansion. The question of replacing tubes which might fail in the rows between the inner and the outer walls certainly presented difficulties; but he thought that operation could be carried out with less delay and expense than, say, the replacement of a set of large furnaces in an ordinary boiler—by no means an uncommon class of repair. There appeared to be no reason for expecting that the tubes would fail individually, any more than did those in ordinary boilers when properly worked. The Author had not supplied any data by which the weight of his boiler per indicated HP. could be compared with that of the usual form; but without figures, it evidently would compare favourably in that respect with any form hitherto used at sea. The point which he thought should first claim the attention of those interested in the attainment of high speeds at sea, was the suitability of this boiler to the application of forced draught. Referring to the results of Professor Kennedy's trial E, it appeared that even under a forced draught of 2 inches water-gauge, the boiler had a higher evaporative efficiency than usually shown by the ordinary type of boiler under natural draught. He thought any one who had experience of the latter form (especially if double-ended) would bear him out that it could not be worked for long under a forced draught of 2 inches water-gauge without leaking. He believed the only risk with the Thornycroft boiler at sea would be from burning the tubes if the condenser leaked seriously; or in the event of a greater waste of water taking place than could be made good by the evaporators. Speaking from his experience with ships making long voyages, he did not consider either contingency likely to happen except under unusual circumstances, and they could be guarded against, to some extent, by carrying a reserve of fresh water in the double bottom of the ship—a practice frequently adopted. The effect of oily deposit during a long voyage was, he

thought, not likely to be a serious cause of trouble, as with care the use of oil, for internal lubrication and for lubricating the piston-rods and valve-spindles, could be reduced to a minimum; and such deposit would, by the rapid circulation through the tubes, probably be prevented from lodging there, and would be found in the upper or the two lower receivers which were not exposed to the direct action of the fire. The Author had in his later boilers got over the pitting and corrosion which he had found to occur in the steel tubes by substituting tubes of brass. For torpedo-boats, where maximum efficiency was all-important, no doubt he was wise in so doing; but if this type of boiler was adopted on the large scale, then the higher cost of brass compared with iron tubes would be a serious consideration, especially as the former were liable to great variation in price. He, however, saw no difficulty in effectually protecting the iron or steel tubes of this boiler. It simply involved putting into metallic contact with the iron or steel a sufficient area of zinc plates in the water space of the three large receivers. He had found that the proportion of zinc surface required in the ordinary type of boiler was about $\frac{1}{200}$ part of the internal wetted surface. The protection of boilers from corrosion by the application of zinc, referred to by Mr. Woods, was generally known as the Admiralty system. What he had tried to do, was to ensure efficient metallic contact between the zinc and the steel of the boiler, by a simple copper-wire contact. He exhibited three pieces of zinc showing the application of this contact. The two oxidized pieces had been taken from boilers after some months' use. In one case the wire was still soldered into the zinc; this piece had been in a boiler worked at 65 lbs. pressure per square inch. The other oxidized piece showed the wire quite loose, the solder having become detached by oxidation. It had been taken from a boiler worked at 150 lbs. pressure. The new unoxidized piece of zinc had in it a screwed copper plug with a copper wire brazed to it, no solder being used. He was now trying this form of contact, but could not yet say whether it would prove successful. The only copper used was the small wire making the contact, except in the case of the last-described method, where a small screwed plug was added. There were several questions in connection with the water-tube form of boiler under discussion, which only extended experience in the working of it could decide. It might be found that the outside surface of the tubes forming the firebox arch, wore away where the hot gases passed between them above the two lower receivers. Internal wasting might also take place at the water-line in iron or steel Mr. List.

Mr. List. tubes, if the boiler was kept for long periods under banked fires. As, however, steam could be raised very rapidly in boilers of this form, it would probably be better, instead of keeping them lying with fires banked, to have one of a set only under steam, and to blow the water from the others into the double bottom of the ship, from which source they could be quickly filled again by steam-pumps. If this method of working were adopted, he thought that steam could be raised to full pressure in all the boilers in less time than would be required with a set of boilers of the existing type having all the fires banked. To prevent external corrosion when the boilers were not under steam, the tubes if of iron or steel would have to be kept free from accumulations of soot and dirt, and perfectly dry; this, however, could be easily accomplished. In conclusion, he was of opinion that the Thornycroft boiler had great merits. From the fact that it was designed on scientific principles, was correct in mechanical construction, and was being successfully worked, it stood widely apart from any form of marine water-tube boiler hitherto tried. The circulation in it was exceedingly good, it was light and strong, could be put together *in situ*, was especially adapted to the application of forced draught, and had a high evaporative efficiency which was well maintained even with unusually high rates of combustion. He thought that, by the adoption of boilers of this type, another distinct step would be made towards greater economy of fuel on the one hand, or increased speeds at sea on the other; and that, as the inventor of this boiler, no less than as the pioneer of high-speed torpedo-vessels, the Author had done work which would have a lasting influence on the progress of steam navigation.

Mr. Flannery. Mr. J. F. Flannery observed that some investigations made by him about ten years ago had been referred to in the Paper, and he thought it only right to say that the Author appeared to have taken up the subject of water-tube boilers where other engineers had left it ten or twelve years since, and had practically worked out a very great improvement, and undoubtedly a successful water-tube boiler for torpedo-boats. How far it might be successful for the class of work that Mr. List had referred to, experience alone could show. Engineers had tried, a few years ago, to get a boiler for marine purposes that would bear higher pressures of steam than were then possible, and most of them, at that moment, looked in the direction of water-tube boilers. But the improvement in steel stopped that, and it had been found possible to construct the ordinary marine multitubular boiler, capable of standing 180 lbs. pressure per square inch. It did not seem likely, however, that

any material would again admit of maintaining the present shape of boiler with still further increased pressure; and for further economy, by higher pressure and greater evaporative duty, he did not know any more likely opportunity, especially after what had been done in the case of torpedo-boats, than that afforded by the tubulous boiler. The Herreshoff system had the disadvantage of a continually varying amount of fire. No matter how careful the ordinary stoker might be, the intensity of the fire continually altered; and while the mechanical circulation produced by the pump was constant, the variation of circulation could not be maintained in the same manner as that of the heat arising from the fire. The result was that there was either too much circulation, leading to one form of bad working, or too little in proportion to the heat coming out of the fire, leading to another form of bad working. It appeared to him that the Author had produced a boiler which automatically adjusted its circulation to the amount of heat being given off, from moment to moment, by the fire; and the reasoning in the Paper, as far as he was able to judge, was most correct and carefully thought out, showing the mode of circulation, and the evaporation of the water in boilers of that kind, in a way which he did not remember to have seen previously worked out. On the question of the comparative advantages of that type and of boilers of the ordinary marine type, the Paper stated that the boiler in question indicated about 700 HP. He happened to have, at the moment, a new boiler of the ordinary type, to carry 160 lbs. pressure per square inch, of which he had taken the weight accurately, and it was capable of indicating, under the same circumstances of forced work, about 700 HP.; its weight was 40 tons, and the weight of water about 22 tons. If the Author could state what was the weight of his boiler, and the weight of the water in it, he thought it would demonstrate very clearly the advantage that might be obtained in large steamers by the adoption of a system of that kind. The saving in weight was largely due to the reduction in the diameter of the largest vessel containing pressure. The diameter of the boiler of ordinary type to which he had referred was 12 feet 9 inches; the thickness of the shell arising from that diameter was obviously many times greater than the thickness of the shell in the largest cylinder in the Thornycroft boiler, the diameter of which he thought was about 2 feet 6 inches. That made all the difference in the thickness of the shell, and consequently in the weight. It would be interesting to know for how many hours, during the three years the latter boiler had been in use, it was under steam. Mr. Flannery.

Mr. Flannery. Men like Mr. List and himself were interested in dealing with vessels that were practically continuously under steam—at all events, for thirty days or longer at a time; and, if any comparison could be drawn from the working of the torpedo-boat boiler, they would like to know how many hours during the three years the boiler had been under steam, and what was the greatest number of consecutive hours. The scale on the sections of the tubes was only about as much as was useful for protective purposes. He had found that where thin scale fixed itself to the interior of the shell before corrosion commenced, the effect was similar to that of enamel on the teeth; it protected the boiler better than anything else that could be applied. A vessel that he knew of had boilers of the ordinary type seventeen years old, and they sustained the same pressure as at first, still enjoying the higher classification of Lloyd's Register, the boilers being good in every respect. Comparing the scale with some samples from the tubes of the "Propontis," it would be found that the scale of the latter was $\frac{5}{16}$ inch thick after a short period of work. That was an inadmissible amount of scale—no boiler could stand it; but the scale in the Thornycroft boiler was just sufficient to form a protection, and no more; and if the boiler had been worked during the three years for any large portion of the time, the difficulty with regard to scaling had been effectually solved. He could not quite follow the remarks of Mr. Yarrow with reference to the curved tubes. It appeared to him that straight tubes such as Mr. Yarrow advocated would limit the number of tubes it was possible to join both to the lower and higher cylinders; in order to get the tube to enter at such an angle to the surface of the cylinder that a joint could be made, it must be curved. Straight tubes would practically limit the number to one row, or, at the utmost, two rows. It was true that the curvature made the tubes much more difficult to clean or examine. Did the Author examine his boiler at intervals for safety, and if so, how did he ascertain the condition of the tubes except by cutting them out, which was rather a heroic method? Perhaps he would state whether such a boiler could be examined periodically, as was absolutely necessary in real working. He thought the high duty of the boiler, as proved by Professor Kennedy's report, well showed the amount of encouragement that might be expected from boilers of that kind. The actual duty of the large quantity of water evaporated, independently of the question of high pressure and economy to be obtained, was a matter of very great importance, and indeed was almost startling; and he had no doubt the result would lead

many marine engineers to think about the subject, so that it would not be long before it was found that, as in other respects, torpedo-boats had shown the way for carrying out improvements in large vessels. Mr. Flannery.

Mr. W. Parker observed that when a similar Paper to this was read before the Institution of Naval Architects, in April last, he took the liberty to open the discussion,[1] and if members would refer to the statements made by the gentlemen who took part in that discussion, who had made and worked boilers somewhat similar to the Thornycroft boiler, they would see that the observations he was about to make were of some importance. The Author dwelt particularly upon the reduced weight in such boilers. Mr. Parker wished to state at the outset that reduction in weight of machinery in merchant-ships was not of so much importance as it was in battle-ships. If ship-builders had cut down weights in the machinery of merchant-ships as much as had been done in torpedo-boats and in the Admiralty practice, it would not, in his opinion, have been practicable to run steamers from England to Australia and back again for a period now extending over eight years without hearing of a single breakdown. In his remarks at the meeting of the Institution of Naval Architects, he gave his experience at sea, not in torpedo-boats or steam-launches, but in ocean-going steamers with boilers of this type, and he thought, as a member of The Institution of Civil Engineers, it was his duty to give to the meeting the benefit of that experience. In 1874 a boiler on the principle illustrated by Plate 1, Fig. 2, was fitted in the s.s. "Propontis," and that vessel steamed with this boiler for a period of about two and a-half years. Owing to an engineering error in connecting the two sections at the upper part, a greater pressure existed at times in one section than in the other, so that the one containing the greater pressure became almost empty of water, and in this condition the tubes were exposed to the fierce action of the flame, and in consequence burst, killing some people on board. The owner was naturally much alarmed, but was still inclined to continue the use of the boiler, and would have done so if pitting in the tubes had not taken place to a serious extent. The Author stated (p. 44) in the Paper, "The diameter of the tubes should increase with their length; but when their upper ends are above the normal water-line, like those in the 'Propontis,' Plate 1, Fig. 2*a*, described by Mr. Flannery, there is certainly danger in making them too large. In this case, Mr. Parker.

[1] Transactions of the Institution of Naval Architects, vol. xxx. p. 276.

Mr. Parker. instead of the steam and water passing over in foam, the steam alone will leave the tubes. The impurities brought in with the feed-water will gradually accumulate in the upper part of the tubes, and will lead to their destruction. The Author attributes the failure of the upper ends of the 2½-inch tubes in the 'Propontis' to this cause, and it is possible that obstruction from deposit collected in this manner gave rise to the more serious failure of the large water-chambers at a later date." Mr. Parker wished to state that it was not the upper parts of the tubes of the "Propontis" that gave way; it was the lower parts that pitted, and were the cause of the boiler being condemned. Further, with regard to the lower chambers, there was no deposit in them whatever. He examined them after the explosion, which was caused simply by the water leaving the chamber as described. Long before the "Propontis" boiler was made a number of water-tube boilers of different descriptions had been tried in merchant-ships. The mercantile marine of this country had not been behind the age in spending money, with a view to obtaining higher pressures and a corresponding reduction in fuel. During his own experience with water-tube boilers no less a sum than £200,000 had been spent by steam-ship owners and engineers upon boilers of this type. In 1875 two very large ships were built for a line of mail steamers to run between Liverpool and New York—the "Montana" and the "Dakota." The boilers were almost similar to that shown as the Perkins boiler. It was considered, when those boilers left the Tyne on the vessel's passage to Liverpool, that the circulation in the lower tubes would not be as good as the designer imagined, and there being no means of the water getting down to the tubes, it was thought there would be nothing but steam in them, and that it would be only a question of time for the tube to become red-hot and for the pressure inside to burst it. When the "Montana" left the Tyne he happened to be on board, and sailed with her to Liverpool. There were eight boilers fitted in the ship, and before reaching the Isle of Wight six of these boilers had burst, and the vessel drove for forty hours in the English Channel disabled; had it not been for fine weather she would certainly have drifted ashore. Fortunately the weather was fine, and, with the assistance of tug-boats, she was taken into Portsmouth, repaired, and afterwards sailed to Liverpool. On the passage everything worked well; the engineers and those who had charge of the boilers had fixed to each lower tube a separate feed-pipe, and on the opposite end of each lower tube they had a cock, to ascertain whether water or steam was present. During the passage

Mr. Parker.

it was ascertained, over and over again, that in the lower tubes there was only steam. That was sufficient evidence, to satisfy him, who, as Board of Trade surveyor at the time, was responsible for the safety of these boilers, that she was not a fit and proper vessel to take twelve hundred passengers across the Atlantic. However, after a great deal of negotiation and correspondence, it was decided, in order to prove this, that the vessel should make a trial trip in the Atlantic for six days, and that a Commission appointed by the Admiralty should also attend. He would leave the members to imagine what the cost of such a trial trip would be with a vessel of 5,000 tons and of 4,000 HP. She commenced this trip, and during the first three days two of the boilers gave out, and the owners' representatives were satisfied that this principle of water-tube boilers was defective and dangerous. They accordingly took the boilers out of the ship, and of a sister vessel which was fitted with similar boilers, although steam had never been raised in them, and ordinary boilers were fitted in both ships at a cost of more than £70,000. It had often been said that the boiler to which he had referred differed considerably from the Perkins boiler (Plate 1, Fig. 2), one boiler having large tubes, and the other small tubes. He would now come back to a boiler which had small tubes. It was fitted by a friend of his, who took great interest in these matters, and he, together with his partners, thinking this form of boiler was going to revolutionize marine engineering, bought a ship, and gave an order to a celebrated marine engineering firm to fit it with that boiler, and with an engine of a special design. It was fitted, and the vessel sailed for three or four years, when the boiler was abandoned and taken out. In a letter he had just received that gentleman stated: "I am sorry I was not able to be present at the Institution of Civil Engineers lately when the tubulous boiler of Thornycroft was under discussion; it is a serious question, for in case of failure in plan or construction for durability, it will involve so great a cost in delay and replacing. But these are points rather for the builders and owners than for the Board of Trade; for the question of safety is probably insignificant." Other types of water-tube boilers had also been tried. In 1870, the "Mark Anthony" and the "Fairy Dell," two steamers built in Sunderland, were fitted with water-tube boilers, with the intention of obtaining greater steam-pressure, and consequently greater economy. The "Mark Anthony" sailed from London, and he believed she was one of the pioneer vessels to the fleet that Mr. List now represented. This boiler gave great trouble from the beginning to the end. The vessel was twelve months in getting from London

Mr. Parker. to the Cape of Good Hope and back again; and, on her third voyage from the Mediterranean, one of the boilers gave out in the Bay of Biscay, the vessel fell off in the trough of the sea and foundered. Fortunately all hands were saved; but the underwriters had to pay for the loss. The "Fairy Dell," which was fitted with a similar type of boiler, crossed the North Sea a number of times; but ultimately the boiler gave out, the vessel foundered, and many lives were lost. With these cases in view, and remembering that the province of the society which he represented, namely, Lloyd's Register of Shipping, was to protect the interests of underwriters, shipowners, and merchants, he thought he ought to detail his experience with the boilers of the type that was now under discussion. He admitted that the Thornycroft boiler had a greater circulation than any other boiler, and that it was much lighter than any existing boiler that he knew of; but then the question arose, were engineers to be satisfied with perfect circulation only, without giving due consideration to the question of durability? He had no hesitation in saying, that in the ordinary tank form of boiler there was practically no circulation; but the tank-boiler lasted and gave satisfaction, and it was known that if one of the tubes in the water-tube boiler happened to pit and leak, the boiler would be disabled; it could not be plugged up, it could not be taken out and another tube put in, while in the tank form of boiler tubes pitted and were plugged at sea without any inconvenience. Under these circumstances, was it not better that the mercantile marine should for the present retain a boiler that would not give trouble? Tank-boilers, 14 or 15 feet in diameter, and 10 to 16 feet long, had been running for eighteen or nineteen years without any reduction of pressure, and as far as could be seen they were in good condition. There were boilers, in ships running between England and Australia, under steam for eighty or ninety days. When they returned from such a voyage there was nothing to do but to wash them out with a hose; there was no scale, no deposit. All the difficulty of sediment from oil had been overcome by the use of fresh water for extra supply, and doing with as little oil as possible for the lubrication of the internal parts, so that little or no oil could get through the condenser into the boiler. A boiler treated in that way gave perfect satisfaction. Nevertheless, if the Author would persuade a shipowner to fit his form of boiler in a steam-ship, classed in Lloyd's Register, the surveyors would he happy to receive it and give it a fair trial, being always ready to try anything that tended to improve merchant shipping. At the same time, looking to their experience

with boilers of the water-tube type, it would be their duty to represent to the public on the "character" of the vessel, that such a boiler was an experiment. Mr. Parker.

Mr. JOHN HEAD said that the chemical composition of the chimney gases had not been stated directly; but it might be inferred from Table I that the proportion of free oxygen in these gases was excessive, and that a portion of the oxygen entering the furnace was only partially utilized, passing away as carbonic oxide; so that a great excess of air was used, much heat wasted, and the quantity of water evaporated was consequently less than if perfect combustion had been attained. He also noted that the temperature of the chimney gases was not given. In order to judge of the efficiency of the new boiler this information would be required. Variation in the combustion, when solid fuel was used, was a great objection in all sorts of boilers, and very disadvantageous. Open spaces occurred in the fire, which allowed large volumes of air to pass either wholly or partly unconsumed, and the cold air thus introduced also produced strains in the boiler from unequal expansion and contraction. To overcome these difficulties he had, by direction of Mr. Siemens, been considering the application of gas to the firing of boilers. At the outset he had generally found disadvantages from the loss of heat by converting fuel into gas, owing to the producers being at some distance from the boilers, which in the cases he had to deal with could not be avoided. In an application in Italy, six boilers had been placed at his disposal for gas firing; but these were Lancashire boilers, and a particular setting was adopted at the works, so that the conditions were not so favourable as could have been desired for that purpose. Although the producers were placed much further away from the boilers than was desirable, he had heard that an evaporative power of 8 lbs. of water had recently been obtained per lb. of coal burnt which, considering the circumstances, he thought a very favourable result. He had called the attention of those using the boilers to the fact that the temperature of the chimney gas was higher by 50° Centigrade than it ought to be, and that the proportion of free oxygen in the products of combustion, which was about 8 per cent., was too great, as it meant 40 per cent. of useless air passing through the boilers. When that had been remedied, no doubt the results would be much better. He thought that then 10 lbs. of water would be evaporated per lb. of coal used, which probably would be as good as was obtained with the best ordinary boilers fired with solid fuel, when working regularly; and these results Mr. Head.

Mr. Head. would be coupled with absence of smoke. The boilers he referred to had been working continuously for about fourteen months; but the figures mentioned had been taken from a recent trial extending over seventeen days and nights, during which time the coal used and the water evaporated were carefully noted; this trial could not be objected to as of short duration. If, as he anticipated, by improving the combustion, the excess of air was reduced so as to obtain nearly 10 lbs. of water evaporated per lb. of coal burnt, the applicability of gas-firing to boilers would be solved. In that case, another form of boiler than the Cornish or Lancashire should be adopted for gas-firing, and he thought the Thornycroft water-tube boiler would come in well for that purpose.

Mr. Martin. Mr. W. A. Martin observed that in the arrangement of the furnace the flames got among the tubes very quickly. The tubes had a tendency to cool the flames and to lower the temperature of the gas, which in escaping would not be consumed. In some of the trials the temperature was marked at 500°, which was moderately reasonable; but the heat was not properly utilized for the reason he had mentioned. The quantity of coal consumed in the full-speed trial was said to be 66 lbs. per square foot, which was a very high rate. The water evaporated per square foot of heating-surface was 8½ lbs. In the case of a boiler the trial of which he had recently attended the amount was 14·9 lbs., and evidently when only 8½ lbs. of water were being evaporated per square foot of heating-surface the fire could not be doing its duty. Perhaps the arrangement of the furnaces was objectionable. He did not see how steam could be raised in such a boiler for any length of time without the boiler showing some defects in the steaming power. A trial on a two hours' run was of little value. He was not an advocate for spasmodic steaming, and he did not like the idea of a vessel going out of the harbour, breaking down, and having to turn back again, which he had known to happen on many trial runs. He had tried to burn a boiler that ran for about two years, but without success. He had used water-tube boilers many years ago, when great difficulty was experienced with the tubes; but perhaps they could be obtained of better quality at the present time. The Thornycroft boiler was no doubt a marvellous one, but he thought the pipes would before long get into a bad condition, owing to the constant tremor of the ship. The corrosion of the pipes too was considerable. What provision was there for cleaning them out? He should be glad if the Author would state if the water-tube boiler could produce steam for more than two hours at the rate marked on the diagrams.

Mr. W. B. LEWIS asked the Author if it were true that a little boat fitted with one of his boilers had been sent out to the Missionaries on the Congo six years ago, that the man who watched its building died as soon as it got out; that it had to be put together by persons on the spot who knew nothing about it, and that it had been working since that time without any trouble? Mr. Lewis.

Mr. J. I. THORNYCROFT said, in reply to the discussion, that it was quite true that the boat referred to by Mr. Lewis had been working for six years, and was still in good order. New pieces had been sent out for the engines, but none for the boiler. Another boiler had been made, in anticipation of the failure of the first, but a part of it had been lost. Mr. Grenfell, however, was of opinion that the old boiler would still do good duty. With reference to the remarks of Mr. Parker, his evidence of course should be received with all respect, as bearing the weight of his own great experience, but his argument that the boiler of the "Propontis" resembled that shown in Plate 2, Figs. 12, 13 and 14, was likely to carry more force than it should do. Mr. Parker had stated that in the "Propontis" the failure was due to the water being blown out from one section of the boiler to another, and that large vessels having been deprived of water, although containing no scale, were burst and several persons killed. The fact was that, in that boiler which Mr. Parker said was like that of the "Propontis," there was only one steam-vessel, and there was no chance of the water being driven out, or getting where it should not be. Unlike many water-tube boilers, it had a gauge-glass which gave an excellent indication of the position of the water-level. Mr. Parker had mentioned the great expense that had been incurred in experimenting on water-tube boilers. Certainly the sum was a large one, £200,000. In regard to Mr. Parker's graphic description of the experiments with the "Montana," the boiler was one having large tubes, and yet having a circulation so defective that, putting a steam-cock into the lower-vessels which were most exposed to the fire, steam was found there instead of water, and notwithstanding this fact the experiment was made of going into the Atlantic with a boiler which was manifestly a failure. It was folly to do such a thing; he certainly should not ask any one to make an experiment of that kind. Mr. Parker had rightly stated that what had been done with the Author's boiler was an experiment, and that he admitted, but he might state that the boilers shown by Plate 2, Figs. 12, 13 and 14, had made a voyage to Bombay, being under steam for thirty-five days, without any trouble at all. The matter was, therefore, not Mr. Thornycroft.

Mr. Thornycroft. in an experimental state, like that of the "Montana." He thought it was quite right that the boilers should be taken out of the sister ships referred to without further trial. He need say no more to show the great difference between the old experiments and those which Professor Kennedy had described. Mr. Parker had stated that what Mr. Thornycroft had to offer was a reduction of weight; and that certainly was so. But it was not the only thing which he had offered. The economy of a boiler depended largely on its heating-surface, and if he were allowed the same weight of boiler, he could undertake to save coal. Mr. Parker had also stated that, in the boiler described, a tube could not be plugged if it was destroyed. He understood him to mean that if one tube failed the boiler was really destroyed. A question had been asked, In how short a time could a boiler of that kind be blown down? It was evident that a boiler containing much less water could be blown down in less time. The sudden cooling of a boiler of that description caused no trouble; it might cool very rapidly; the tubes themselves would not suffer, nor the joints, and he did not think that the large cylindrical vessels were likely to suffer, because there were no parts which might contract at a different rate, so as to cause damage. Such being the case, when a boiler of that kind was blown down, a tube could be plugged from inside, the boiler refilled, steam be got up in a short time, and the boiler could be at work again. Of course, it was not supposed that a large vessel would go to sea with one boiler. Mr. Parker had made a point of two ships being lost because they had water-tube boilers. That might have been the case, but they were not boilers similar to the Thornycroft boiler; they were boilers stamped with failure the very moment they were put in the ships. Mr. Parker had given an instance of a boiler working eighteen years which only required washing out, and had no scale. It was now quite possible with tight condensers to keep a boiler perfectly clean. If that was the case, it was a strong argument in favour of water-tube boilers with an efficient circulation. He had placed on the table a brass tube which had been in use much longer than the two hours referred to by Mr. Martin. It had been running at a very high rate for about twelve days continuously, working from morning to night, not with distilled water, but from water supplied by the West Middlesex Water Company, which contained a considerable amount of lime, and there was no blow-off cock fitted to remove any of the lime. Some might have escaped by the safety-valve; the water was exceedingly muddy and dirty at the end of the trial, but the tube was clean. That was the

longest test with the brass tubes. The iron tubes had been working about three years in a torpedo-school training-boat. Mr. Flannery had stated that the weight of a boiler, of 700 HP., was 62 tons, including the water. The weight of the boiler shown in Plate 2, Fig. 12, complete, was $9\frac{1}{3}$ tons, but he would not claim all that saving in working the boiler at 700 HP. The boiler ought not to be put to do as much work as that, but it had done more, and, as far as known, it did not suffer, having shown no damage from fire. As to the examination of the tubes, he did not think they wanted examining inside if pure water were used. In the case of the boiler which the Government had had for about three years, a large quantity of oil went into it, and when it was opened to put the zinc blocks in, it was found to contain a substance like cocoa consisting of dirt and grease. Mr. Yarrow had given some account of the destruction of the boilers in the "Propontis." He thought his reply to Mr. Parker really answered what Mr. Yarrow had said in that respect. With reference to the difficulty of pitting, Mr. List was of opinion that it could be met by putting plenty of zinc in the boiler; but, as has been previously mentioned, the present notion was to use brass tubes because they kept cleaner. Inside an iron tube, if any rust formed it had a tendency to cause the scale to adhere, but the brass tube threw off the scale better. In the Paper he had referred to the fan having been introduced by his father. Sir Frederick Bramwell had seen a fan used in America, he believed at an earlier date, but the date of his father's work was 1856. He had part of a small wheel working a fan, forcing the air under the deck, dated 1856, which was long before the "Ross Winans" was built. Mr. Yarrow seemed to think that 15 B.W.G. was rather thin for the tubes of the boiler. He was afraid Mr. Yarrow had not calculated the thickness of the plates of a boiler of a common type which should have equal strength to these 15 B.W.G. tubes. A boiler 16 feet in diameter should be more than 12 inches thick. Mr. Yarrow had thought that in the Thornycroft boiler there would be a definite water-line in the heating-tubes. That was not the case. Taking the case of a boat running with a hot fire and suddenly stopped, the steam would either be nearly up to blowing-off point, or it would be lower. If it was nearly at the blowing-off point, the valve would immediately lift and the circulation go on as before; if the steam was not up to that point, then the heat would cause the water to circulate and gradually compress more steam into the steam-space; it would become denser there, and work would be done by the fire in raising the temperature of the whole of the water

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Mr. Thornycroft. contained in the boiler up to the increased temperature. He could not agree that there was any tendency to burn the upper portion of the tubes. The brass tube shown on the table was taken from an experimental boiler in which the upper portion of the flue was heated to a very high temperature, and bright flame proceeded from the top of the flue. Notwithstanding the severity of this test there was no damage in the upper part. On first thinking of using brass tubes he feared undue loss of strength would be caused by the high temperature. The profession was indebted to Professor Unwin for some recent important experiments showing the extent to which brass did lose strength with increasing heat. With regard to the question of the air Mr. Yarrow was mistaken; the boiler could be filled with water while there was steam in it, and then there would be no moist air to fill the upper part. A much better practice than filling the boiler with water was to dry it. A boiler of that kind could be well dried, and the Admiralty practice, he believed, was now to dry boilers by means of a small coke fire. When thoroughly dried, quicklime could be put in and the boiler tightly closed. In that way it was filled with dry air, which was better than water. The object of the quicklime was to absorb moisture. The rapid circulation appeared to be sufficient for cleansing the inside of the tubes. As to curved tubes, Mr. Stroudley and others had come to the conclusion that their elasticity enabled them to stand the changing of the temperature better than straight tubes. Even in locomotive boilers he believed that Mr. Webb was curving the tubes somewhat to allow for the unequal expansion. The locomotive boiler with straight tubes had given great trouble from leakage; indeed that was the reason of its being given up. In the new form of boiler there had been no case of leakage in the tube-plate; the only leakage had been through pitting of the iron tubes. Tubes had been perforated after working for a considerable time, but that was not, properly speaking, leakage. Leakage was the passage of water between the tube-plate and the tube, and that, he believed, had not occurred. With reference to grease, the boiler seemed to bear it with impunity. Mr. Yarrow appeared to think that the tubes over the fire would give trouble. The tubes that had given trouble were those that were furthest from the fire. In the case of a boat built for Spain, which was very badly kept and very dirty, the tubes gave considerable trouble on one side but not on the other. The boat probably had a little list, and the tubes on one side were horizontal at the upper part, while the others were inclined. Thus drops of water formed by condensation probably collected on one side, and

were absent on the other, so that one side decayed and the other did not. Mr. Yarrow had made some remarks as to the duty he had got out of a tubulous boiler with straight tubes without any trouble, and considered the 100 HP. per ton obtained was a very good result. Mr. Thornycroft would say that it was a good result if economy was secured at the same time, but it appeared to him that it was too much for economy. In the experimental boiler, working with the brass tube, a duty had been obtained equivalent to about 220 HP. per ton. Mr. Mair-Rumley seemed to hold the opinion that a Cornish boiler ought to be as efficient as the Thornycroft boiler. He wished to point out several differences. Mr. Mair-Rumley had really explained the matter, because he had said that the Author had sought how to get a large amount of heating-surface in a small compass; that involved getting a large amount of surface with small external radiating-surface, and that would account, to some extent, for the small radiation. He admitted that Professor Unwin was right in saying that it was almost getting too small radiation. With reference to the alleged waste of oxygen, it was not possible to use all the oxygen that was put into a furnace; an excess must be supplied in order to get good combustion. In trial E, when only 17·2 lbs. of air were admitted per lb. of coal, considerable loss was suffered through the formation of carbonic oxide. It was to be regretted that in Mr. Mair-Rumley's trial the furnace gases were not analyzed, because such analysis was always of interest, and often showed how improvements could be obtained. He thought Mr. Mair-Rumley would have seen by an analysis that he was not using sufficient air, and this deficiency was quite enough to explain the inferior efficiency of his boiler. The experiments recorded in the Paper were the first carefully-conducted experiments made with the boiler. There would not have been so much waste in carbonic oxide, as was shown, if the experiments had been made before. The heat lost by imperfect combustion was quite a large amount in some of the experiments. He was much indebted to Professor Kennedy, not only for the Appendix to the Paper, but also for his remarks, which elucidated some of the important points of the trials of the boiler, and he further called attention to the fact that the engine-test was not very fair to the engines. The Author wished to explain that the donkey-pumps, which were great offenders by using too much steam, were removed after the trials, and others substituted; although this was perhaps unnecessary, these pumps being only required in actual work, when the ordinary pumps driven by the main engines had broken down. The temperature of the stoke-hold

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Mr. Thornycroft. under forced and natural draught, given by Professor Kennedy, was important, as showing that the popular notion as to the inconvenience of closed stoke-holds was incorrect. In some trials, where it was important to burn as little coal as possible, steam was used for one auxiliary engine only, and this for circulating water in the condenser. The result was very satisfactory as far as coal consumption was concerned, but the heat of the stoke-hold was much increased. Mr. Bryan's experience with water-tube boilers, at the East London Water-Works, was of interest, and his testimony as to the dryness of the steam was valuable. The very small consumption of water by the engine seemed itself to be an evidence that the steam was dry. His remarks on the large radiation experienced did not, however, apply to a boiler similar to that brought before the meeting. In the Babcock-Wilcox boiler, the heating-tubes themselves did not form an external wall or covering; it was only the separator which took this function. Consequently, when the boiler was under steam, a large surface of firebrick was exposed to a temperature higher than that of the steam in the boiler; and although this might not involve much loss when a number of boilers were placed side by side and worked continuously, it was likely to do so, as suggested by Mr. Bryan, when only worked intermittently. The zinc plates in the upper chamber of the boiler were intended to arrest oxidation, as Mr. Woods supposed. There were also zinc plates in the lower chambers. He was of opinion that Professor Kennedy was right in remarking upon the large range of evaporation within which the boiler could be economically worked, and he did not agree with Professor Unwin that it was purely a function of the forced draught, or that any boiler, if it would stand a variation of draught such as was used in the trials, would evaporate a correspondingly different quantity of water. He could agree that it would burn a correspondingly different quantity of coal; but in a first-rate marine boiler the ratio of heating-surface to fire-grate was only about 30 to 1, while the heating-surface used in the water-tube boiler trials varied from sixty to seventy times the area of grate, or more than double that of the best marine practice. The evident effect of this change of proportion was to utilize the heated gases produced to a much greater extent when the fire was severely forced. To take an extreme case for illustration, it might be easily conceived, when a very small heating-surface only was used for a given area of grate, that the products of combustion might pass the entire heating-surface, and yet retain a very high temperature, even when natural draught only was used. The result of forcing

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the fire in this case would be to slightly increase the evaporation, by bringing the heated gases more rapidly in contact with the heating-surface; but the increase would be due rather to the greater number of heated atoms coming in contact with the surface, than to their increased temperature. The principal effect of the increased coal consumption in such a boiler would be a greater volume of flame in the funnel. Mr. Wingfield had quoted figures from actual experiment which supported this view. Professor Unwin objected that the trials were short ones. As regarded those at low speed, there was some force in this objection; but they had to be made in the Thames in November, and longer trials were impossible, on account of the shortness of the days and the prevalent fogs. The absolute duration of a trial was not a fair measure of its length as compared with other trials. With very slow combustion, particularly combined with a heavy boiler containing a large amount of water, changes took place so slowly in the steam-pressure, water-level, and condition of the fire, that it was difficult to estimate when a particular critical point had arrived; but, given very rapid combustion, small weight, and small quantity of water, a particular phase might be determined within a very short interval. He would not, therefore, wish to put out of sight the two hours' trial, as Professor Unwin had kindly suggested, as he took it that, from this trial, quantities might be measured with perhaps as great accuracy as those taken from a trial under the conditions of Mr. Mair-Rumley's; for as much coal was burnt on each foot of fire-grate in two hours, in the one case, as was burned in eighteen hours in the other. Professor Unwin was a little mistaken as to the way in which the condition of the fire was estimated at the beginning and end of the trials. It was not attempted to get a fire of equal thickness, for it was impossible to estimate the value of a fire in this way. By running the engine at a definite speed for a little while before the commencement, and maintaining this speed unaltered during the trial, the amount of steam taken from the boiler could be depended on as regular. The fires, at the commencement, did not contain green coal, but were allowed to burn down until they would no longer maintain the steam-pressure. In trial D the fire was exceedingly thin, and at both start and finish it would be seen that the steam-pressure was falling. With regard to the ashes put on the fire, these were really good fuel, containing 83 per cent. of carbon. The bars were not intended for this low rate of combustion, and were too far apart; so that, with a thin fire, coal was liable to fall through when simply split up by the heat. Estimated in this way, the volume

Mr. Thornycroft. of fire due to the quantity of incombustible matter in it at the end of the trial was a matter of no consequence, and did not affect the accuracy of the result obtained. There was, perhaps, some force in the objection that the 1·9 per cent. loss by radiation in trial D was too small; but it was also true that the loss due to furnace gases was more difficult to measure than the heat given to the steam. He would therefore claim that it was at least equally fair to take it from the one as from the other. It was observed that there was no loss due to smoke in trial D, but there was some loss from this cause in the trials at higher speed of working. He thought Professor Unwin had put too liberal a value on the possibility of error in the experiment considered. Mr. Spencer saw difficulty in firing so large a grate as was used in the experiments. This difficulty was imagined by considering a fire in an ordinary flue, where there was not room to throw the coal without striking the top of the furnace; a longer fire could be worked with advantage in a high furnace than could be managed in a low one, and extra width did not seem to affect the matter, except to give better or more complete combustion. He was glad to have Mr. Spencer's support on this point. In answer to Mr. Cowper, he thought large size of tube was not favourable to success, except when discharging below water-mark. The cause of failure in large tubes had been given in the Paper. To get high duty from the fuel required attention to the fire at frequent intervals, in any kind of boiler. Admiral Selwyn had made some remarks, to the effect that the tubes were only retained in the tube-plates by ferrules and ordinary expansion. As a matter of fact, no ferrules were used, expansion in the tube-plate affording ample security for a good joint and freedom from danger of the tubes being blown out. He considered that in using thin tubes, if the ends could be threaded and screwed in, the reduction of strength due to the thread would more than compensate for any advantage that could be gained. Mr. Stroudley had directed attention to the fact that in the blacksmith's tuyere a similar method of circulation as that adopted by the Author had long been employed, and the tube used was not blocked by incrustation, although exposed to a very intense and local heat. The only difficulty in this was that of making repairs in the present form of boiler. This difficulty, he thought, was not so great as had been suggested by several speakers. If a tube failed at the inner part of the system, several other tubes would have to be removed before it could be got at; but these tubes could be removed and replaced again with little difficulty; being long in proportion to their diameter their curved form gave

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them great elasticity, and the ends of a tube could be moved relatively to each other through a considerable distance without causing any permanent bend. This enabled them to be adjusted in their place although not quite accurately bent. He did not consider Mr. Hodge's description of the boiler gave a correct idea. In what were known as vertical boilers, the gases usually escaped from the upper part of the firebox, while in the Thornycroft boiler there was a large volume in the firebox above any point where the gases could escape, and the heating-surface was not vertical, as described by Mr. Hodge, but inclined. Mr. Duckham was anxious to accept the high evaporation obtained by the boiler, while he at the same time took away the means by which this was obtained. The tubes were not curved in the particular way in which he found them, to allow for the difference of expansion between those which were more particularly under the influence of heat, and those which were less heated, but were curved so as most conveniently to form a firebox and flues, while, at the same time, the separator was protected from heat. This, he believed, could not be done with straight tubes, even if otherwise unobjectionable. Mr. Willans wished to know if any statistics could be produced as to the efficiency of the separator. He had not tried any experiments to determine this point; but the working of the engines tended to show that less water came over than with the locomotive boilers previously used, and he thought what Professor Kennedy had said was conclusive as to the comparative dryness of the steam in trial D, where the highest evaporation was obtained. When the boiler was worked very hard, sometimes a little priming was evident; but in the experiments water had been kept especially low in the separator, with a view to prevent this; and the fact that all the heat was accounted for seemed to indicate there could not be much water passing over with the steam. Mr. Willans had taken the consumption of steam by the engines as an indication that the steam was wet; but it had already been explained that the proper feed-pumps delivering into a tank in the stoke-hold, all the feed-water had to be pumped a second time, and against the full boiler-pressure, by a donkey-pump, in such bad order, that when used intermittently on the first trial, the amount of steam taken was so great that a fall of pressure could be at once detected when it was set in motion. But to settle this question of dryness of steam he hoped to make some experiments, the result of which he should have pleasure in making known at some future time. In examining the calculations made by Mr. Halpin, he found that a trial of the water-tube boiler

Mr. Thornycroft. had been taken when the rate of working was not so rapid as in the trial of the locomotive with which it was compared. If he had taken trial B, where the economy of evaporation was more nearly the same, he would have obtained 66 as the value of the factor. Instead of being 9 per cent. less than that obtained from the locomotive, it was 32 per cent. greater. For trial E, that at the highest rate of working, it would be above 80. Mr. List had discussed the suitability of the boiler for ocean steaming, and it appeared probable that a field was open here where high speed or very long voyages rendered saving in coal important. Unfortunately, information about the performance of marine boilers was at present not sufficiently complete to enable him to give an exact comparison. In the figures given by Mr. List, the boiler efficiency was obscured by being taken together with that of the engines. The great weight, however, of the boilers was evident; and the fact that a much larger heating-surface could be given in the same space showed that the ordinary boilers brought forward by Mr. List might be displaced with considerable advantage, both in the decreased weight of boilers and weight of coal to be carried. Mr. List believed that the only danger to be feared with the Thornycroft boiler at sea would be from burning the tubes if the condenser leaked considerably, or in the event of greater leakage than could be made up by the evaporators. In order to avoid leakage of condenser tubes, Mr. Normand of Havre had modified the form of his condenser, making all the tubes curved, the segment of a large circle. This construction did not appear to involve any serious difficulties, and Mr. Normand had informed Mr. Thornycroft that these curved tubes, simply expanded into the plate, kept perfectly tight, and were not liable to leak after being out of use a short time, as was the case with the ordinary condenser. This construction evidently formed a solution for one of Mr. List's difficulties. In his opinion Mr. John Head was not justified in comparing the combustion of mixed gases with the combustion of solid fuel on the same terms. Although in the experiments a certain amount of free oxygen passed up the funnel, in most of them the result would have been better had this quantity been greater. The results obtained by Mr. Head in firing boilers by producer gas were, as he suggested, not very favourable, and this was probably due to the causes named. He was of the opinion, however, that if the fuel in a ship was to be turned into gas, it might perhaps be burnt in the cylinder of the engine with advantage. This view was held by the late Sir William Siemens; but if a steam-boiler must be used, it would no doubt be most convenient

to regulate all the fires by simply opening or closing a valve. It would have been interesting if Mr. Head would have mentioned in how small a space, and of what weight, the gas producer could be made for some particular amount of evaporation. Mr. Thornycroft.

Correspondence.

Mr. W. Inglis said he had taken a good deal of interest at one time in this kind of boiler, especially as regarded the circulation through the tubes, having designed two types with this feature particularly in view, in 1863, and several had been made about that time by Messrs. Sir W. G. Armstrong and Co. and other firms. He had also read a short Paper on water-tube boilers at the meeting of the British Association for the Advancement of Science held at Newcastle-on-Tyne in that year, when he exhibited a working model of his water-tube boiler with the tubes made in glass, to show the perfect circulation of the water through them. The advantage of this circulation of the water had been, he thought, satisfactorily proved from some of the boilers he made about 1864 having been in constant use night and day at paper-mills near Edinburgh, where, two years ago, he saw them still at work, and he was informed that two of the boilers had been in use till April last, when they were taken out after working for twenty-five years. Each of them was equal in capacity or steaming-power to an ordinary Lancashire boiler 7 feet in diameter and 30 feet long. He thought the Author was right in aiming at having a very free circulation of the water. In nearly all the water-tube boilers brought out in recent years, arrangements for securing or promoting circulation had been more or less imperfect or neglected altogether. Mr. Inglis.

Mr. W. Kilvington believed there was an impression that water-tube boilers were more economical of fuel than smoke-tube boilers. But there was no reason so far as he could see why this should be so; and he did not know of any experiments which proved it. He could not think why a smoke-tube boiler should not be as economical as any other, because good combustion could be got in properly-proportioned furnaces, the gases in the chimney could be kept at a moderate temperature, and, as the heat could not from the construction of the boiler be lost in any considerable quantity by radiation, it must have gone into the water and so raised steam. The circulation might not be so good and Mr. Kilvington.

Mr. Kilvington. the steam-space might have to be larger. But in viewing boilers generally, he thought it would be admitted that the passage of the products of combustion from the fires to the uptake, in such a way that they were brought in contact with all the heating-surface, was quite as important as the circulation of the water inside, and this was provided for in the ordinary marine type of boiler more surely than was the case with most water-tube boilers. It did not appear that the experiments of Professor Kennedy exhibited any economy in the Thornycroft boilers over good examples of the usual marine type; for, although series D, Table I, showed a very large efficiency, namely, 86·8 per cent., yet, when the easy conditions of the trial were taken into account, it was not so extraordinary, for the boiler had more than 9 square feet of heating-surface to absorb the heat from each lb. of coal burnt per hour. He thought an equal efficiency might be predicted for an ordinary smoke-tube boiler of the common marine type worked under the same easy conditions, and this assumption appeared the more probable on examining series B, Table I. It would be seen that here the quantity of water evaporated from the temperature of the feed was 9·6 lbs., and the heating-surface was a little more than 2 square feet for each lb. of coal burnt per hour. This was about the ratio of heating-surface with which hundreds of marine boilers worked at sea, which certainly evaporated 10 lbs. and upwards of water per lb. of fuel, so that their efficiency would exceed that of the boiler under consideration. Boilers of the water-tube type were thought to be a necessity when high pressures were first mooted for use at sea; but now boilers of exactly the same type as were used for pressures of 60 to 80 lbs. were daily made to work at 150 to 170 lbs. per square inch, and were in every way successful. Undoubtedly the boiler under discussion was an excellent one, but still he was firmly persuaded that the time was far distant when water-tube boilers would be employed at sea, except in cases where extreme lightness was imperative.

Mr. Kirk. Mr. A. C. Kirk remarked that the boilers of the "Propontis" had been designed by Mr. Rowan, and were, he understood, practically duplicates of boilers previously worked with success on the "Ganges." It was to utilize the exceptionally high pressure of steam afforded by them that he designed the three-crank triple-expansion engines; and it was the failure of these boilers that prevented him from repeating them till about eleven years later, when they were adopted in the s.s. "Aberdeen." Soon after, this type of engine became almost universal. The failure of Mr. Rowan's

water-tube boilers caused Mr. Dixon, of Liverpool, to substitute boilers of the ordinary type for 90 lbs. pressure only, with which the original engines worked for a number of years. These boilers had been lately replaced by boilers of the ordinary type, but of the full pressure of the original water-tube kind; and with these the original triple-expansion engines were still doing excellent work. The original water-tube boilers were a failure. While in good order they generated steam well and economically, but they gave out by the pitting of the tubes, and ultimately failed from the chamber over the fire bursting through getting empty of water. Mr. Rowan's earlier boilers were small, having only one furnace, with a water-chamber and vertical tubes on each side of the furnace, and a chamber over the fire. From these three chambers bent tubes ascended to a fourth horizontal chamber, into which the water, as it spouted up mixed with steam, was discharged. To better separate the water from the steam, the upper chamber had a short vertical steam-drum from which the steam was withdrawn. The three lower chambers were connected at the back of the boiler by large iron pipes, a little less in diameter than the chambers themselves, and extending to the upper chamber, affording a free passage back to the lower chambers for the water projected into the upper chambers. In the "Propontis," two of these boilers were grouped into one; the lower chambers were connected by the large circulating pipe at the back, and the steam-domes by a pipe forming part of the steam-pipe of the engine. On trial, the water in the gauge-glasses oscillated several feet in an unaccountable way; ultimately this was found to be due to the free water connection at the bottoms, while the steam connection at the top was more restricted, and opposed greater resistance to the passage of steam than the lower connection did to that of water. The result was, that when one fire was fired harder than the other, the water-level in that compartment was depressed; and when a fire was raked, the fire-door of the other compartment had to be opened to keep the variation of the water-level within safe limits. When carefully and equally fired, all went well; but at last the water-level in one of the boilers fell so low that the chamber over the fire got nearly red-hot and burst. This ended the boilers. But long before this the tubes pitted very seriously in the upper part. How far this was due to the excessive variation of water-level leaving the upper portions of the tubes empty of water, like the older super-heaters which pitted and wasted rapidly; or how far to ignorance on the part of the engineers on board the ship, combined with the evil effect of using animal oils or tallow in the cylinders, and the Mr. Kirk.

Mr. Kirk. decomposing action on them of high-pressure steam, which was not then appreciated in the universal way it was now, he did not know. The bad arrangement which led to the explosion need not be repeated; and, if pitting could be prevented, there was no reason why this boiler, or modifications of it, should not be a success.

Mr. Park. Mr. J. C. PARK observed that although he had no personal experience of water-tube boilers, yet, as he had for the last thirty years been engaged in the construction and working of locomotive and other boilers, he might make some remarks based on practical experience. It was evident from the trials made by Professor Kennedy that the evaporative power of the Thornycroft water-tube boiler exceeded that of any ordinary locomotive type weight for weight. But its sensitiveness to changes in the fire and feed was no doubt due to the large grate area and limited quantity of water and steam-space contained in the boiler, requiring greater skill and watchfulness on the part of those in charge. He thought that few engineers holding responsible positions would care to admit that this type of boiler afforded sufficient facilities for dealing with the failures of tubes under steam, as often happened with the best modern marine and locomotive boilers. In railway practice scarcely a week or, he might say, a day passed without new brass or steel tubes giving way in a most unexpected manner. Tube makers attributed these failures to the tube expander, but under any circumstances the less complicated a tubular boiler was, the better. Failure of the curved tubes, and the difficulty that must be experienced in making them tight or replacing them, seemed to be a weak point in this class of boiler, and he did not see how the necessary cleaning of the tubes inside and outside could be carried out expeditiously. A saving of material was claimed by the Author; but material of a more costly character in the form of brass tubes was employed. It would, therefore, be interesting if the Author would give the cost of the new boiler as compared with the locomotive torpedo type, also the cost of repairs during the three years of its existence, and the number of miles run during that period. In railway practice a set of brass tubes would last for 150,000 to 200,000 miles, and when supplied of superior quality, such as were obtained twenty years ago, the average on the North London Railway was 300,000 miles. Having, in 1874, heard much in favour of the efficiency of the Field boiler, due to superior circulation, he had adopted one on that railway in connection with the steam-hammer furnace, but owing to the ends of the tubes burning away rapidly, a boiler of the locomotive type had been substituted. The Author was to be congratulated for his ability and perse-

Mr. Park.

verance in bringing out this boiler, which, theoretically, might be considered almost perfect; and if the mechanical difficulty of dealing with the tubes in cases of failure could be overcome, he felt sure it would have a great future.

Captain Rasmussen.

Captain A. Rasmussen, Sub Director of the Royal Dockyard, Copenhagen, observed that at present the Danish Navy possessed thirteen Thornycroft water-tube steam-boilers fitted in nine torpedo-boats, which had been in service for long periods during the last three years, and arrangements had been made for seven others to be fitted partly in new boats, partly in older ones, where originally locomotive boilers had been used. It afforded him much pleasure in bringing before the Institution his experience in working them.

Boilers of the types hitherto generally adopted for war-ships must be treated with the greatest care when under steam. Fires had to be lighted several hours before steaming commenced, great fluctuations in steam-pressure, when under way, must be avoided, and when a run at full power was over, it was inadvisable to stop the engines suddenly, and steaming had to be continued for some time to work the boiler-pressure down. These precautions were not likely to be taken by the commander of a ship in time of war. Cases might often occur when steam would be quickly raised, the fires forced, and the engines run at their highest speed, and then, perhaps, suddenly stopped. In most cases this would be accompanied by leakage of some of the tubes, and every time a sudden change in the forcing of the boilers was repeated, the tubes would get more and more leaky, until finally it would be impossible to maintain the water-level above the highest part of the heating-surface, steaming would have to be discontinued, and the ship would be at the mercy of the enemy.

The ordinary boilers for marine engines possessed many other disadvantages. The tubes were most inefficient as a heating-surface; when forcing the fires by artificial draught the gases rushed in unbroken streams at a great speed through the tubes, the flame being extinguished at the entrance of the tube, and only a small amount of heat was transferred through the greatest part of them, the combustion sometimes taking place in the uptake and funnel. In the inside of the boiler the water circulation was most confused at the tubes, if there existed any circulation at all. Was it possible to conceive conditions more inimical to circulation than those which were met with at the sides of the firebox in the "dry-bottom" locomotive boiler? The difficulties in keeping the

Captain Rasmussen. flat, stayed surfaces of fireboxes and combustion chambers free of scale, which generally settled down where the water circulation was bad, were well known, as also the weakness inherent to the circular furnace, which had to support a heavy external pressure while exposed to a high temperature, and unable to transmit the heat readily to the water by reason of a layer of grease or scale deposited upon it. As it was considered by Captain Nielsen, the Director of the Danish Dockyard, that the above difficulties with the common boiler were of such a nature as to make it merely a question of time when water-tube boilers would take their place in war-ships, he decided in 1886 to abandon the locomotive boiler and adopt the Thornycroft water-tube boilers for some torpedo-boats, which at that time were ordered for the Danish Navy. The first four boats in which these boilers were fitted were of about 100-tons displacement, and had triple-expansion engines of 1,300 indicated HP., steam being produced at a pressure of 200 lbs. per square inch in two water-tube boilers placed in one boiler-room. The result was eminently satisfactory. The boilers did not need any special care or treatment, and any speed of engines, which the commander of the boat at any moment might desire, could be obtained at very short notice, and without any fear of putting the boiler *hors de combat* from leaky tubes.

Amongst naval officers and engineers, who had served in boats where these boilers were fitted, there had been but one opinion, that the boiler was a great improvement. Steam was generally raised in twenty to thirty minutes. The steam-pressure could be raised 100 lbs. per square inch in a few minutes. The engines could be stopped suddenly from full speed, with active fires on, without any sudden rise in steam-pressure or any appearance of water. During torpedo practice last summer one boat had been stopped suddenly four hundred and sixty times when running at speeds varying from 3 to 21 knots an hour, and of these one hundred and seventy-seven times at full speed (about 21 knots); still the boilers in the boat were in as good a condition as ever, and not a drop of water had appeared at the tube ends. Priming occurred only very rarely. When the boilers did prime the water notwithstanding was quiet in the water-gauges, these being on the steam separator where the water-level was not disturbed. The chance of a boiler explosion was very remote, because the boiler had not any flat surfaces which could be exposed to the fire uncovered by water, should the water fall below the lowest permissible level. From a small boat, which capsized last summer while steaming, the boiler was afterwards taken out for inspection, when not the least sign of weakness,

leakage, or overheating of the boiler, could be detected. Fresh, not distilled, water had hitherto to be used in the boilers. No scale had as yet been found on the interior surfaces. It seemed not improbable that salt water might be employed as supplementary feed-water, provided an arrangement for the precipitation of the salt in the separator of the boiler proved successful. Should this be the case, the feeding arrangements could be simplified considerably. It must, however, be remembered that in this respect there was an advantage from the water of the Danish seas having a comparatively low density. The boiler-tubes were cleaned from soot in a few minutes, and only at long intervals, because the soot could not settle down on the nearly vertical and convex surfaces. The suitability of the boilers for high pressure need not be further commented on. Leaving the question of the direct saving of money aside, the principal advantages in a war-ship fitted with boilers, which worked economically, were, that the smaller coal consumption enlarged the radius of action, and that the absence of flame and sparks from the funnels rendered the ship or boat less liable to attract attention. These advantages would certainly be manifest in war-time. The perfect combustion in these boilers had been borne out in all the experiments. Thus, in a small torpedo-boat of about 26 tons displacement, having triple-expansion engines of 350 indicated HP. and one water-tube boiler, working at 250 lbs. pressure per square inch, the coal consumption was at the most economical HP., 1·9 lb. per indicated HP. per hour, and at full power 2·6 lbs. per hour, in which latter case 28 indicated HP. was developed per square foot of grate at an air-pressure of 3½ inches. The coal used on these trials contained a good deal of dust. In round numbers the coal consumption was 2½ lbs. per indicated HP. per hour with the water-tube boiler, as against 3½ lbs. with the locomotive boiler, in boats having the same size and type of engines and about the same boiler-pressure. The saving in weight would appear from the following Table, in which the weight of the boilers, with mountings and all fittings, as well as the weight of water in the boilers, was given in lbs. per HP. developed at full power forced-draught trials:—

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Type of Boiler.	Boilers with all Fittings in Boiler-room.	Water in Boilers.
	Lbs.	Lbs.
Low cylindrical	80	44
Locomotive	33	11
Water-tube	29	7

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In this comparison the weight per HP. was taken from a gun-boat with two low cylindrical boilers, a torpedo-boat with one locomotive boiler, and a torpedo-boat with two water-tube boilers. In boats with only one water-tube boiler the weight per HP. of boiler and its water was somewhat less than the above. Where possible, two water-tube boilers were fitted in the Danish torpedo-boats. Should one give way, the boat could still be propelled at a speed only a few knots lower than the speed obtained with both boilers in working condition. Should a leakage from any cause occur in one of these boilers, it was rather difficult to find the damaged tube and substitute a new one. Leakages might occur at the weld of lap-welded tubes and at corroded parts of the tubes. As the steam-pressure tended to make the union between the cylinders and the tubes tight, and not, as in common boilers, to open it out, there was not much probability of a leakage at the tube ends, the unequal expansion due to change of temperature being taken up in the bend of the tubes. To avoid leakage altogether it was therefore only necessary to employ solid drawn tubes, and tubes which did not corrode. The tubes had hitherto been of steel, and in one of the boilers they had given a good deal of trouble from pitting of the interior surface. As small globules of lead were found in several of the rust-cones at the bottom of the pits, he attributed the corrosion to the galvanic action between the lead and the steel. To overcome this, the only difficulty experienced with the Thornycroft boilers, the tubes had been made of brass in those now under construction for the Danish Navy. As a rule, the water-tube boilers were taken out of the boats when the cruise was over to get them properly examined and cleaned, as was formerly done in boats fitted with locomotive boilers. This did not entail much extra expense; besides, the bottom plating under the boilers could be properly cleaned and repainted. In large ships, to be fitted with these boilers, it was intended to arrange them in such a way that they could be thoroughly overhauled and the tubes examined, and fresh ones substituted if necessary, without taking the boilers out of the ship. The heating-surface was, however, so ample that a large number of tubes might be stopped at the ends with patent stoppers, should they for some reason or other become damaged, without the steam production being materially affected. The Author had given a sketch of a steam joint with a copper ring, the ends of which were brazed together. This joint had for several years given great satisfaction, except that in some cases galvanic action had taken place between the copper ring and the boiler, which was slightly corroded in the line

of contact with the ring. The copper ring had lately been tinned, but he did not know yet if this would stop the galvanic action. Captain Rasmussen.

Having had such good experience with the Thornycroft boiler, the Danish naval authorities naturally desired to employ it in large ships. Hitherto only two boilers had worked together in one boiler-room; but for large ships the question arose, would these boilers with the small steam room, and the small amount of water they contained, work well together? In the first place due allowance must be made for the proportionate reduction in steam production, which would accompany the larger number of boilers, because they could not be forced to the same extent as one boiler or two boilers. But there were several other points to consider. In engines supplied with steam from two sets of ordinary boilers, one set arranged forward of the other, and each set placed in a separate boiler-room, the steam from the forward set of boilers would have a lower pressure at the junction of its main steam-pipe with the main steam-pipe from the aftermost set than the steam generated in this set, supposing the same boiler-pressure to be kept in all the boilers. As, however, the pressure in the main steam-pipe fluctuated considerably during each stroke of the engines, the forward set of boilers could only deliver its steam to the engines during a shorter period than the other set. The consequence would be that the aftermost set would supply more steam to the engines than the forward set. To obviate this, a few lbs. higher pressure, namely, so much as corresponded to the fall in pressure in the steam-pipe between the boiler-rooms, must be kept in the forward boilers, and the safety-valves loaded accordingly. This might not seem to bear directly on the question of water-tube boilers; indirectly, however, he believed that the fluctuation, or, as it might be called, the pulsation of the steam in the steam-pipe, must be taken into consideration, where boilers with small spaces for steam and for water were to work successfully together in a large ship. In a torpedo-boat engine running up to 650 revolutions a minute, the steam was drawn nearly continuously from the boilers, and the pulsation, caused by the drop in steam-pressure during admission to the high-pressure cylinder, and the following rise in pressure during the rest of the stroke, would only take place in the steam-pipe, the time which each stroke lasted being so short, that the pulsation did not reach the boiler. If the cut-off in the high-pressure cylinder took place at the end of the stroke, the steam would be continuously formed in the boiler, and equally continuously taken by the engines; in this case there would not be any pulsation at all, but only a fall in pressure in

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the steam-pipe due to friction, and the pressure would be constant during the stroke throughout the steam-pipe. To ascertain the amount of this pulsation some trials had recently been made in a small torpedo-boat; the results were given in the Table, p. 131. Besides the two usual indicators on the high-pressure and low-pressure cylinders, indicators were placed (1) on the high-pressure valve-casing; (2) on the steam-pipe; (3) on the boiler, with a short pipe leading to the inside of the interior steam-pipe; and (4) on the boiler with a short pipe leading to within 2 inches of the water-level. The interior steam-pipe terminated in a stop-valve, called in the Table the boiler stop-valve, while the engine stop-valve mentioned in the Table referred to a straightway-valve on the steam-pipe about 2 feet distant from the valve-casing.

In trials Nos. 1, 2, 3, 7, and 11, the valves were full open, the slide-gear was put at latest cut-off, but the steam-pressure was different, except in trials 2 and 3; in these the steam-pressure was intended to be the same, but the boiler primed heavily on trial 2, while the water in the boiler was quiet when the diagrams on trial 3 were taken. In trials 4 and 8, the steam was wire-drawn at the engine stop-valve, while the boiler stop-valve throttled the steam in trials 5 and 9. On trial 6 the steam was expanded further by the slide-gear, so as to obtain about the same HP. as on trials 3, 4, and 5. Likewise on trial 10 the steam was cut off early to get about the same HP. as was developed on trials 7, 8, and 9. The pulsation in the valve-casing or steam-pipe was measured by the difference between the maximum and the minimum pressure; it might easily be calculated on the assumption that the steam expanded according to Boyle's law, which in this case could not be far from the truth. Taking, for example, trial 3, the volume of the steam in the high-pressure cylinder, when cut-off took place, was 0·18 cubic foot; the crank had then turned through 104°. The steam used by the engines was produced continuously during the stroke, but only $\frac{26}{45}$ of it could pass directly to the cylinder; the rest, or $\frac{19}{45}$ 0·18 = 0·076 cubic foot of steam, caused pulsation in the steam-pipe. The maximum pressure in the steam-pipe, just before admission took place, was 49 lbs. and the volume of steam-pipe and valve-casing 0·63 cubic foot. Then $(49 + 14{\cdot}7)\ 0{\cdot}63 = (49 + 14{\cdot}7 \div \Delta\, x)\ (0{\cdot}63 + 0{\cdot}076)$ where $\Delta\, x$ = pulsation in lbs. This equation gave $\Delta\, x = 6{\cdot}9$ lbs.; on the trial it was 7 lbs. The pulsation on the other trials might be calculated in a similar way, assuming as above that the pulsation did not reach the steam-space in the boiler, which in this case was correct, because the indicators leading to the steam-space did

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Trial No.	Revolutions per minute.	Boiler-Pressure by Indicator.	Indicated HP.	Slide-valve Gear.	Boiler Stop-valve.	Engine Stop-valve.	In Steam-pipe.			In Valve-casing.			Remarks.
							Maximum Pressure.	Minimum Pressure.	Mean Pressure.	Maximum Pressure.	Minimum Pressure.	Mean Pressure.	
		lbs.					lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
1	246	17·5	14	In full gear	Full open	Full open	18·5	16·2	16·6	18·0	15·4	16·1	Priming.
2	268	39·5	18	"	"	"	36·5	32·8	33·6	36·0	32·8	32·7	"
3	327	46·0	35	"	"	"	49·0	42·0	44·5	38·0	32·0	34·4	A little priming.
4	328	87·0	34	"	"	2 turns open	87·0	87·0	87·0	44·0	33·0	36·9	
5	336	91·0	35	"	½ turn open	Full open	42·0	35·0	37·5	42·0	35·0	38·1	
6	335	92·0	41	Linked up	Full open	"	96·0	87·0	92·5	94·0	84·0	89·4	Occasionally priming.
7	430	90·0	65	In full gear	"	"	94·0	83·0	88·1	84·0	68·0	77·5	
8	427	138·0	68	"	"	2 turns open	138·0	138·0	138·0	78·0	60·0	68·5	
9	426	138·0	73	"	¾ turn open	Full open	76·0	66·0	71·4	78·0	66·0	69·2	
10	421	139·0	73	Linked up	Full open	"	143·0	128·0	138·0	145·0	124·0	139·0	Steam rather wet.
11	508	136·0	113	In full gear	"	"	136·0	120·0	129·0	134·0	112·0	125·0	

Captain Rasmussen. not move. Although the weakest springs which the boiler-pressure would allow without the indicator-piston being pressed against the stop were used, the indicators were not sensitive enough to show the small pulsation which on several of the trials had most probably taken place when the boiler primed. The earlier the cut-off, the greater became the pulsation, because the ratio between the amount of steam generated in the boiler while the high-pressure piston travelled from the position of cut-off to the end of the stroke, and the steam generated during admission to the high-pressure cylinder, increased with the ratio of expansion. The above trials also afforded testimony to the well known quieting influence on the steam production in the boiler obtained by wire-drawing the steam on its way to the engines, this being specially the case when the wire-drawing took place near the engines. Trials 4 and 8 proved that the pulsation did not penetrate to the boiler side of a stop-valve somewhat closed to obtain the wire-drawing. When the stop-valves were full open, the pulsation diminished, and the mean pressure increased regularly from the engines towards the boiler.[1]

In a large ship the number of revolutions was necessarily limited on account of the screw; the steam-space in the high-pressure cylinder, as well as the time which the admission to this cylinder lasted, became therefore greater, the pulsation increased, and perhaps had time enough to reach the steam-space in the boiler. Should this be the case, where the boilers were low with small steam-space and imperfect water circulation, it might be inferred that even the faintest fluctuation of steam-pressure at the water-level

[1] The pulsation of the steam might often be the cause of the difference in initial pressure, which was frequently seen in admission lines from top and bottom high-pressure cards, a difference which engineers often attributed to wire-drawing in steam passages of the cylinder, or in the indicator pipes. When the steam rushed into the valve-chest, its pressure rose at the wall opposite the steam-pipe, because here the kinetic energy of the steam was transformed to pressure, and the steam would be admitted at a higher pressure in one end of the cylinder than in the other. On the above trials, where the steam was not wire-drawn, it would be seen that the sudden stopping of the steam raised the maximum pressure in the steam-pipe above the boiler-pressure; trial No. 2 was an exception, but in this trial the circumstances were abnormal on account of the priming. In many cases he thought the pulsation might be the cause of the bursting of a steam-pipe. During manufacture it was perhaps weakened by overheating of the copper, and during steaming the pipe was exposed to constantly repeated stretching between given limits of stress. (In No. 11 of the above experiments the pressure rose and fell 22 lbs. in the valve-casing, and 16 lbs. in the steam-pipe, over one thousand times in a minute.)

would cause constant priming, and that the boilers would be totally unfit for continuous steaming. How water-tube boilers behaved in this respect he did not know, but they had two points in their favour, that the water which the boiler contained in the separator was not put in constant agitation by the generation of steam from heating-surfaces beneath; and that the generation of steam in the tubes was so dependent upon the consumption, that a small and sudden variation in pressure would only cause a comparatively greater or smaller volume of water to pass with the steam from the tubes into the separator, where the necessary arrangements were found for the separation of the water from the steam. In boilers for large, slow-running paddle engines, pulsation was guarded against by giving them a large and high steam-space. No doubt the distance between the internal steam-pipe and the water-level played an important part; the steam-dome, for example, was beneficial, not only because it increased the steam-space, but especially because it kept the pulsation from reaching the water-level. In comparing different types of boilers he had used a constant, involving the product of the time which the admission lasted, and the pulsation expressed in lbs., the pulsation being calculated on the assumption that the whole steam-space took part in the pulsation. Although the assumption was not correct, yet the constant gave some idea of the working of the boiler with respect to regularity of the production of steam. In the Thornycroft boiler steam-domes could not be used, at least in the Danish Navy; the height of the boiler would not allow this. To keep the pulsation from affecting the water-level of the water-tube boilers in large ships, the steam-pipes must have, by the insertion of steam collectors, a suitable volume, and be so arranged that each individual boiler shall have to produce and deliver to the engines the same amount of steam; also the highest boiler-pressure and number of revolutions which the other requirements would permit ought to be used, because the steam-filled space would be thereby diminished at cut-off in the high-pressure cylinder, as well as the time which the admission lasted. It would be tempting to increase the pressure in the boiler and wire-draw the steam a little on its way to the engines, but unfortunately the wire-drawing was accompanied by a decrease in the weight of steam passing to the engines. Captain Rasmussen.

Another circumstance, which affected the question of water-tube boilers in large ships, was the absolute size of the steam-space proper. The steam-space must regulate the steam production, and supply or store up the steam, which constituted the difference

Captain Rasmussen. between the steam taken by the engine and the steam generated in the boiler. The variations in pressure caused thereby might be called forth by an alteration either in the speed of the engines or in the supply of air, stoking or feeding of the boilers. The steam-space in different types of boilers might, therefore, always be compared to the number of seconds in which it could supply steam to the engines, and not by cubic feet per HP., especially because nowadays such different boiler-pressures were used. The more active the circulation, the less steam-space was necessary, because any variation in pressure would quickly be followed by an equivalent increase or decrease in steam production; while in a boiler with feeble circulation, a variation in pressure in the steam-space would be accompanied by priming, if it was not very small and gradual. As these variations became greater when a large number of boilers had to work together than when a single boiler was used, the size of the steam-space must be increased with the number of boilers. This would be specially necessary when the boilers were not equidistant from the engines, measured along the steam-pipes. When these points as to pulsation and variation in steam-pressure, as well as to the proportionate increase in heating-surface with the number of boilers, were taken properly into account, he could see no reason why a number of boilers of the Thornycroft type should not work successfully together in large ships, having given such good results in torpedo-boats. He had not here entered upon the relative cost of water-tube and ordinary boilers; should there not be any difference of importance in this respect between the two types, it might safely be asserted that before long the usual boiler would be abandoned and its place taken by water-tube boilers. At all events, the Thornycroft boiler possessed, as a steam generator for war-vessels, most important advantages as to simplicity in treatment, security against explosions, economy in construction, and saving in weight.

Professor Smith. Professor R. H. SMITH thought it might be interesting to compare the results of these boiler-tests with a formula which he had developed in a series of articles on "Boiler Power and Heating Surface," published in "Industries,"[1] in 1887. Here the phrase "Boiler Heat Horse-Power," shortly written B.H.HP., was used to mean the quantity of heat expressed in foot-lbs. conducted per minute into the water and steam divided by 33,000. Also the "Boiler Mechanical Horse-Power," shortly written B.M.HP., was defined to be the "mechanical work in foot-lbs. done per minute

[1] Vol. iii. pp. 1, 27, 413.

by the evaporation of water into steam divided by 33,000"; that was $\frac{p\,v}{33,000}$, if p was the steam-pressure in lbs. per square foot, and v the cubic feet of steam produced per minute. The formula arrived at for the relation between heating-surface, boiler power, and boiler efficiency was— Professor Smith.

$$\frac{\text{S}}{\text{B. H. HP.}} = \rho\,\gamma\,\{1 + 0\cdot08\,d\}\left\{\frac{1 - 0\cdot02\,n}{1 - 0\cdot0002\,n\,t}\right\}\left\{\frac{n^{1+2e}}{50\,(1 - e)}\right\}$$

where S = heating-surface in square feet;

ρ = factor to allow for loss by radiation and conduction from outside shell of boiler and by incomplete combustion;

γ = factor to allow for loss by diminution of conductivity by sludge and scaling, and sooting of the plates;

d = mean hydraulic depth of the flues in inches;

n = ratio of actual air-supply to that chemically required for complete combustion;

t = excess of steam temperature over outside air temperature in Fahrenheit degrees;

e = furnace and boiler efficiency, that was, ratio of heat received by water and steam to the heat generated by combustion in the furnace.

The factor 50 was chosen by reference to the experiments of Peclet on conduction from hot gas to water through an iron plate. e was the same as was called the "boiler efficiency" in the report upon the Thornycroft boiler. In the following Table the quantities in lines 1, 2, 3 and 4 were quoted from that report for tests D, C, B and E; lines 5, 6, 7, 8, 9 and 10 were calculated from the figures given in the report; and 11, 12 and 13 were calculated from the above formula, using the data supplied by the report. Line 6, or the values of n, was calculated from the "lbs. of air per lb. of fuel," as stated by Professor Kennedy, and from the 11·5 lbs. of air stated by him, page 60, to be chemically required for the complete combustion of the coal actually used. It must be noted, however, that the values of n given for experiments A and D, pages 60 and 61, namely 2·10 and 1·62 did not agree with the other quantities, but corresponded respectively to 11·4 and 11·2 lbs. of air chemically required instead of 11·5 lbs.

Professor Smith.

TESTS of the THORNYCROFT WATER-TUBE BOILER.

	Reference letter of trial . . .	D	C	B	E
1	Boiler efficiency $= e$	0·868	0·814	0·782	0·666
2	Ratio of loss by radiation, incomplete combustion, &c. $= 1 - \frac{1}{\rho}$	0·024	0·036	0·073	0·131
3	Air temperature, Fahrenheit . .	69°·3	71°·4	60°·3	62°·1
4	Steam temperature, Fahrenheit .	380°·2	375°·5	365°·5	379°·6
5	Steam temperature − air temperature $= t$	311	304	305	317
6	Lbs. of air per lb. of coal ÷ 11·5 $= n$	1·58	1·55	1·51	1·50
7	Evaporative power per hour from and at 212° Fahrenheit . .	2,723	6,970	10,154	18,000
8	Heat HP. = B. H. HP.	1,028	2,630	3,832	6,793
9	Square feet heating-surface per heat HP. $= \frac{S}{B.H.HP.}$ . . .	1·7870	0·6985	0·4795	0·2704
10	Factor ρ calculated from line 2 .	1·0246	1·0370	1·0790	1·1510
11	$(1+0{\cdot}08\,d)\frac{1-0{\cdot}02\,n}{1-0{\cdot}0002\,n\,t}\cdot\frac{n^{1+2e}}{50\,(1-e)}$	0·6285	0·4367	0·3383	0·1983
12	Line 11 multiplied by ρ from line 10	0·644	0·453	0·365	0·228
13	Line 9 divided by line 12 $= \gamma$.	2·77	1·54	1·31	1·18

In line 11 the calculation had been made taking the mean hydraulic depth d as $2\frac{1}{2}$ inches. This was the volume of the space filled with hot gas to which the heating-surface was exposed, divided by the heating-surface. He had been able to make only a very rough calculation of this volume from the small scale drawing accompanying the Paper. If the value of d were as much as $5\frac{1}{4}$ inches, the smallest value of γ (line 13, test E) would be reduced to unity. The value of γ was really the ratio of the rate of heat conduction per square foot of heating-surface in Peclet's experiments to the same rate in the actual boiler considered, the conditions of difference of temperature on the two sides of the plate being taken the same. This rate of conduction depended not only on the material and condition of the plates, but also to a great extent upon the thorough mixing of the currents of hot gas, and the

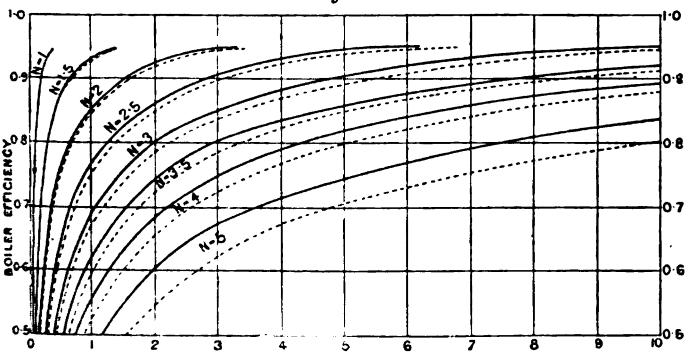
Professor Smith.

TABLE of the FUNCTION $\left\{\frac{1 - 0 \cdot 02\, n}{1 - 0 \cdot 0002\, n\, t} \cdot \frac{n^{1+2e}}{50\,(1-e)}\right\}$ OCCURRING in the FORMULA

$$\frac{\text{Square feet heating-surface}}{\text{Boiler heat HP.}} = \rho\,\gamma\,(1 + 0 \cdot 08\, d'')\left\{\frac{1 - 0 \cdot 02\, n}{1 - 0 \cdot 0002\, n\, t} \cdot \frac{n^{1+2e}}{50\,(1-e)}\right\}$$

n	*e*	*t* 250	*t* 300	*t* 350	*t* 400	*t* 250	*t* 300	*t* 350	*t* 400	*e*	*n*
1·0	0·5	0·0412	0·0417	0·0421	0·0426	0·398	0·414	0·428	0·445	0·5	3·0
	0·6	0·0514	0·0521	0·0527	0·0532	0·619	0·643	0·667	0·693	0·6	
	0·7	0·0688	0·0695	0·0702	0·0710	1·029	1·067	1·108	1·152	0·7	
	0·8	0·103	0·105	0·105	0·1065	1·924	1·994	2·070	2·152	0·8	
	0·9	0·206	0·2085	0·211	0·213	4·79	4·97	5·16	5·36	0·9	
	0·95	0·413	0·417	0·421	0·426	10·72	11·08	11·50	11·97	0·95	
1·5	0·5	0·094	0·096	0·097	0·099	0·553	0·577	0·604	0·634	0·5	3·5
	0·6	0·128	0·130	0·132	0·1345	0·888	0·926	0·969	1·017	0·6	
	0·7	0·184	0·187	0·190	0·1944	1·518	1·587	1·660	1·737	0·7	
	0·8	0·301	0·306	0·311	0·316	2·93	3·06	3·20	3·35	0·8	
	0·9	0·653	0·662	0·673	0·686	7·52	7·86	8·22	8·60	0·9	
	0·95	1·360	1·382	1·405	1·428	17·06	17·81	18·60	19·46	0·95	
2·0	0·5	0·171	0·174	0·178	0·183	0·736	0·775	0·817	0·866	0·5	4·0
	0·6	0·245	0·250	0·256	0·263	1·214	1·277	1·348	1·428	0·6	
	0·7	0·375	0·383	0·392	0·402	2·14	2·25	2·37	2·51	0·7	
	0·8	0·647	0·662	0·677	0·693	4·23	4·45	4·70	4·97	0·8	
	0·9	1·485	1·519	1·555	1·592	11·16	11·76	12·41	13·12	0·9	
	0·95	3·185	3·257	3·333	3·413	25·63	26·98	28·47	30·15	0·95	
2·5	0·5	0·271	0·279	0·288	0·298	1·20	1·29	1·39	1·50	0·5	5·0
	0·6	0·407	0·419	0·432	0·446	2·07	2·22	2·39	2·59	0·6	
	0·7	0·653	0·672	0·692	0·713	3·81	4·08	4·39	4·76	0·7	
	0·8	1·176	1·209	1·247	1·290	7·88	8·44	9·09	9·85	0·8	
	0·9	2·824	2·907	2·996	3·090	21·7	23·3	26·1	27·2	0·9	
	0·95	6·192	6·374	6·566	6·772	51·1	54·7	58·9	63·8	0·95	

Fig. 6.



The full-line curves give the values for $t = 250°$, and the dotted curves the values for $t = 400°$.

Professor Smith.

good circulation of the water and steam on the other side of the heating plates. The high value of γ for trial D, namely, 2·77, was probably accounted for by sluggish circulation in the water-tubes when the rate of working was less than one-sixth of the full boiler power. The numerical results of the formula were given in the Table and in the diagram, *Fig. 6*, p. 137.

Mr. du Temple.

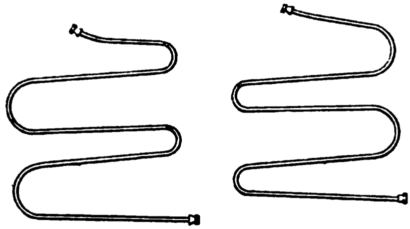
Mr. F. DU TEMPLE, although he did not share in all the views enunciated by the Author, nevertheless agreed with him on certain points. Without attempting to establish a parallel between the boiler under discussion and his own, he might express his approval of the employment of small tubes, and the rules that experience had led him to adopt. Below 0·354 inch internal diameter, the column of water that the tube contained was too quickly turned into steam to effectually protect the tube against a strong fire; but, starting from 0·374 inch internal and 0·512 inch external diameter, a tube even 14·8 feet long could support the fiercest fire provided the bends that the tubes made were all so inclined to the horizontal, that the circulation was neither hindered nor stopped by the effort necessary to cross that part of the tube where the water would tend to collect. These tubes supplied a considerable quantity of steam, 7·175 lbs. an hour per square foot of surface with ordinary draught, 20·500 lbs. under forced draught. They were too readily filled with incrustation because of this enormous evaporation, unless granitic or distilled waters were employed. They suited only certain particular cases. The tube of 0·512 inch internal and 0·669 inch external diameter was that which he had adopted for all large double torpedo-boat boilers. Very good results followed from giving a relative length one-half less than that of the 0·374 inch and 0·512 inch tubes; but already their production of steam was sensibly lessened, 5·125 lbs. of steam only per square foot of heating-surface per hour with ordinary draught, 14·350 lbs. with forced draught, with a grate occupying almost all the breadth and length of the space formed by the tubes. Tubes of 0·669 inch internal and 0·866 inch external diameter, began to come under the category of tubes of large dimensions, and no longer offered the smallest advantages—for instance, considerable production of steam, safety, facility of bending and fitness, &c., as would be seen later on, and the Author with his large tubes required 25 per cent. more heating surface than Mr. du Temple did to generate the same amount of steam. The boilers consisted of a cylindrical collector above, in connection with one or two lower and smaller rectangular collectors, according as the boiler was a simple one like the Author's, or a double one like his own, com-

Mr. du Temple.

municating, say, by two or four series of steel tubes bent into an S shape in the interior of the hearth, and on the outside by several large return-tubes. The water filled these tubes and collectors up to about one-third of the higher collector. The small tubes only being exposed to the fire, the water in them became heated, rose to the upper collector, where it gave up the particles of steam that it contained, then descended by the large external tubes to the lower collectors, to pass up again by the small tubes. This cycle realized a continuous automatic circulation of all the water contained in the boiler, resulting from the difference of temperature between the exterior and the interior of the furnace, and by a disposition based upon the action of plunging- or diving-tubes. This continuous circulation going on inside the small tubes enabled them to resist the fiercest fire, which indeed only acted to increase the circulation, especially if there was a large consumption of steam. Circulation diminished sensibly during prolonged stoppages if a big fire were maintained, unless some steam were allowed to escape into the air, or were sent to the surface-condensers, for in such cases equality of temperature ensued, which lessened the circulation or entirely destroyed it. The bends of the smallest tubes nearest to the fire would only contain a mixture of steam and water, and would risk pitting, on account of their relatively considerable thickness. As a fact, his steel tubes, when used with a surface-condenser, did not burn, save after long service or by entire neglect of the attentions referred to. Tubes of pure copper or of bronze had been tried by Mr. du Temple, but he had abandoned them. After a short wear, this metal, when used for tubes of small diameter, appeared to decompose, became brittle, and lost all its tenacity. The steam-supply, which in his first boiler was provided by the upper cylindrical collector, now only came from the lower collectors, being contained in brass tubes which passed through the whole length of these rectangular collectors. The space in his boilers was always equally divided, half water and half steam. This proportion sufficed to allow the steam fed to the engine to be immediately replaced without surface ebullition. A larger quantity of water induced priming, while a smaller quantity rendered the boiler too sensitive to variations of temperature of the furnace. His small tubes always terminated below water-level, so that the steam was disengaged as in tubeless boilers. Unless the water were allowed to reach much above the proper level, the steam was, at all pressures, as dry as possible, without recourse to artificial device. He was the first to adopt the arrangement of

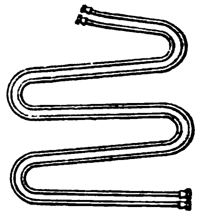
Mr. du Temple. an upper superior collector placed above the smaller lateral collectors, connected together by four series of small tubeways. Although the Author had credited him with a great advance in this employment of small tubes, Mr. du Temple regretted that he had not thought fit to accord to him the priority of this disposition of boiler, seeing that it had been under trial for eight months on one of the Author's torpedo-boats, No. 14, sold to the French Navy, and that long before the Author had constructed any of his own form of water-tube boilers. During the course of these experiments, which were made in 1883, Mr. du Temple unsuccessfully tried tubes terminating above water-level. With the pitting of the tubes the steam became damp as dry air with rain. His tubes, all independent one from the other, were easily put in by hand, without, so to speak, touching their neighbours. They were joined

Figs. 7.



Interior. Exterior.

Fig. 8.

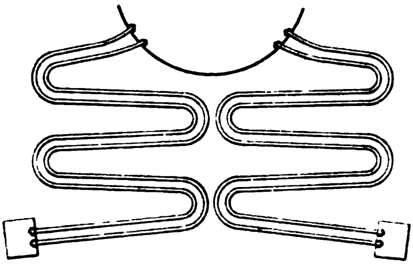


to the collectors without any rings (*garnitures*), and so effectively that several of his boilers containing four hundred and ninety-six tubes, nine hundred and ninety-two joints; tested cold at 284 lbs. per square inch, they had borne the test without the slightest leak. Such a boiler could be mounted in twenty-four hours, and dismounted in less, at the bottom of the vessel that contained it. There were only two kinds of tubes, of the same length, the interior and the exterior (*Figs. 7*); inclosed one within the other, they formed *Fig. 8*; and placed on each side of the collector they formed *Fig. 9*. The interval between the groups allowed of another group being placed a little lower down, so that the bends seemed to fill the intervals of those of their neighbours. In *Fig. 10* the four groups could be well seen. Movable panels, weighing for the largest boilers only 80 lbs., and consequently capable of being lifted by one man, formed the top of the casing, kept in place only by keys easily taken out. By removing the panel in front of the bystander, every tube could be rapidly taken out and replaced. These panels, slightly inclined outside from top to bottom, were only licked by

Mr. du Temple.

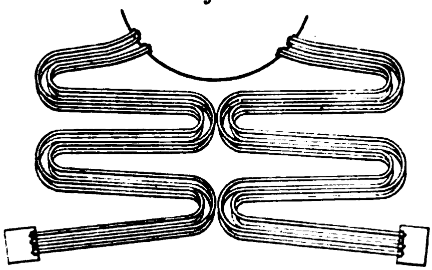
the flames. The walls of the firebox were alone lined with fire-bricks. The boiler with 904 square feet of heating-surface and 28 square feet of fire-bar surface, weighed with all fittings, chimney, ashbox, &c., from 13,640 to 13,860 lbs. The water it contained, 176 gallons, made up the total working weight to about 15,400 lbs., which could be diminished by about 450 lbs. if refractory bricks

Fig. 9.



of less weight were put in. This boiler gave, per hour, 10,450 lbs. of steam at 140 lbs. pressure with 1,650 lbs. of coal and 3½ inches of air-pressure, and 10,000 lbs. of steam with 1,430 lbs. of coal and 2½ inches of air-pressure; below this air-pressure the economy of coal became considerable. Every part of this boiler was either cylindrical or spherical, the upper collector, 27½ inches in diameter,

Fig. 10.



had the thickness of locomotive boilers of 55 inches diameter. Tested to 280 lbs. pressure, it could work up to 180 or 195 lbs. The small tubes were so strong that even when split they worked occasionally for a long time, only letting off a small thread of steam or film of water, which had not much influence on the total production. During five years that Mr. du Temple's boilers had been tested and employed, when thousands of tubes had been used, only one accident had occurred arising from a badly-made tube

Mr. du Temple. which opened out at a low pressure, and obliged the torpedo-boat to be towed home. The fire was partly extinguished, and the boiler emptied itself without any projection of steam or water outside the firebox. He would refer to two incidents, not accidents, which showed the safety of his boiler. On board torpedo-boat No. 20, some miles out at sea from Cherbourg, the single pump of the engine became ungeared, the donkey-pump refused to work, the pressure rose in the boiler. Mr. du Temple raised the safety-valves and drew the fire a little to the front. Then he got on deck to know what had happened. During his absence the stokers, who were inexperienced, leaving the safety-valves open, spread the fire again to make it burn out more quickly. Soon after they came up to inform him that the boiler was red-hot. He asked the captain to have the donkey-pump worked by hand through its fly-wheel. The water entered the tubes, which were as red as the fire, and the pressure rose violently. He lifted the safety-valves, the tubes became black again from below, and the steam already formed allowed the donkey-pump to work, the boiler filled, and the torpedo-boat got back without being injured. One of his boilers for torpedo-boat No. 54 was tested with closed chambers before being put into the boat. It worked at 135 lbs. pressure. The steam escaping into the open air roared furiously. All at once silence intervened; the gauges, graduated to 228 lbs., instantly rose to the highest point. It was desired to raise the safety-valves, but found to be impossible under the peculiar circumstances. It was attempted to feed the boiler, but the donkey-pump would not work, its gauge, graduated to 170 lbs., showed the needle twisted round its pivot. The fire was drawn, and at the end of ten minutes the pressure reappeared on the gauge. The key of the rod of the regulator-valve was broken and the valve would not act. The safety-valves were blocked. Thus the boiler was suddenly closed under a full fire. How high the pressure rose could not be ascertained, but it must have been at least 25 or 30 atmospheres, and this not gradually but with the violence of a blow. Nothing was injured. The key was replaced, the safety-valves were put right, and the trials continued. He would conclude by saying that these incidents had been mentioned because they were very rare; they would still more rarely be produced voluntarily even by the most enthusiastic inventor.

Mr. Thornycroft. Mr. J. I. Thornycroft, in reply to the correspondence, said he was glad Mr. Inglis's experience had been so satisfactory in this kind of boiler during so long a period. In comparing the economy of water-tube boilers with the ordinary type, described as smoke-

Mr. Thornycroft.

tube boilers, Mr. Kilvington had overlooked a very important difference in the two kinds. He was no doubt correct in saying that, given good combustion, and the gases cooled down by contact with the heating-surface to the same temperature, the economy of all types of boilers must be much alike. The important difference was the greatly increased weight of the ordinary boiler. The weight per square foot of heating-surface of a marine boiler in ordinary practice might be taken as about 70 lbs. including water, whereas in this water-tube boiler it was only about 12 lbs. Evidently, therefore, it was not possible to use so large a heating-surface in the case of the ordinary marine boiler, and economy must from this cause suffer. Mr. Kilvington described the products of combustion as passing from the fires to the uptake, in such a way as to be brought in contact with all the heating-surface. It had, however, been found that the hot gases passing through straight tubes did not give up their heat well, because the currents were not broken up in the favourable manner in which this took place when passing across a system of water-tubes. He thought Mr. Kilvington did not attach sufficient importance to the circulation inside the boiler. Two great evils resulted from defective circulation; the first was a loss of economy resulting from an increased temperature of the heating-surface, which naturally led to the second evil, namely, the more rapid destruction of the boiler, which was further hastened by the accumulation of sediment, as described in the Paper. The Author demurred to the description of trial B, as one in which the boiler was worked under easy conditions; for it was well known that many boilers had given out under similar conditions—that was, with ½-inch of air-pressure in the stokehold; and comparing the HP. obtained on this trial per foot of fire-grate, it would be found to be 25 per cent. greater than was practicable in ordinary marine boilers. He was pleased to find that Mr. Kirk, with his great experience of water-tube boilers, was of opinion that, if pitting could be prevented, there was no reason why they should not be a success. The sensitiveness of the boiler to change of feed, described by the Author, seemed to have been a little misunderstood by Mr. Park. It depended upon two things—the continued priming of the generating tubes, and the small quantity of water in the boiler. The first led to a very steady water-level in the glass when the feed was regular, and the second necessarily made the addition of a small quantity of water apparent; and both these conditions were advantageous. Although a small change in the feed-supply was apparent, the safe limits of water-level were very wide compared to an ordinary boiler. It was by no means specially sensitive

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In the cylinders of a locomotive engine running with the steam shut off, the variation of pressure due to arrested motion was, however, even greater than that found by Captain Rasmussen, as would be expected from the different nature of the fluids. In view of the increased pressures now used, Captain Rasmussen's remarks upon this subject came at a time when they were of great value. He was indebted to Professor Smith for the trouble he had taken in attempting to put a water-tube boiler into the elaborate formula which he had devised, and regretted that the hydraulic mean depth should present rather a formidable difficulty. If the gases passed in a line parallel to the axis of the tubes, and these were straight, he felt that there would still be difficulty in estimating the value of d; but as the tubes were not straight, and he believed the gases did not move as described, the problem became further complicated. These differences from the previous assumption tended to diminish the hydraulic mean depth, and he thought the value must be less than that assumed by Professor Smith. As to the cause which might account for the high value of γ, for trial D, he had explained in the Paper, that, in order to get a good result, the area of the flues must be so limited that the velocity of the gases in them should cause such a sensible resistance, as to prevent the unequal escape of the hotter gases. When the boiler was worked at a rate so much under its maximum, this result could only be imperfectly obtained, and it was probable that the explanation of the abnormal value of γ lay here. It would be easily understood that when no damper was used in the chimney, if air were entirely excluded from the ash-pit and furnace, so that the flow of gases through the boiler proper was made to cease, the boiler would lose heat by convection, cold air entering the top of the funnel, and finding its way down one part of the section of the flues, while heated air escaped by another. This action did not go on probably in trial D; but with a very small flow of heated gases through the boiler, the cooler portion would tend to stagnate in one part of the flue, while the hotter gases escaped in too short a time through another. There was also a different explanation which might partly account for the same thing:—The boiler was considerably sooted during the first trial, and was only efficiently cleaned previous to the later forced-draught trials. He was glad that Mr. du Temple had given his views on his own boiler, as well as the one under discussion. He differed from him as to the best diameter of tubes which could be used. It must be borne in mind that the fact that the ends of the tubes being always submerged might render a small diameter

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advisable. Mr. du Temple, in his experiments upon tubes of different sizes, appeared to find a higher rate of evaporation per unit of surface with small tubes, and attributed the lower rate in the larger tubes simply to the increase in diameter. There was no apparent reason for this, and it would seem possible that some other element, which had been changed, had had more effect upon the evaporation than Mr. du Temple expected. These very small tubes were, as he himself said, only suitable for special cases, and it would appear, from two facts mentioned by him, that tubes of 0·512 inch internal diameter were not large enough to ensure their always being effectively cooled by the circulating water. The facts referred to were these. A steel tube opened out at a low pressure, and discharged the water into the firebox. Now this particular tube had presumably stood the water-test; but if subjected to a strong fire when only a low pressure, as described, was in the boiler, the volume of steam produced might be unable to escape from the upper end of the tube with sufficient rapidity to prevent its being overheated. This point was illustrated in Plate 2, Fig. 10, where the increase of weight of steam which could be generated in a particular tube was shown to depend upon the pressure. His experience with copper and bronze also indicated that his tubes were a little too small in diameter, at any rate for the use of these materials, brass tubes of $\frac{7}{8}$-inch internal diameter having been found by the Author to stand hard firing for a considerable time without any deterioration being apparent. He could not quite agree with Mr. du Temple's remarks concerning circulation. Difference of temperature could not directly cause circulation; it could only operate indirectly by changing the volume; and addition of heat to the water might do this, by the production of steam, without affecting the temperature. The cessation of circulation described by Mr. du Temple did not seem to be within the practical limits of working. Equality of temperature could only be attained when the water and steam had acquired the temperature of the fire, and steam must escape somewhere long before this, or an explosion must ensue. Mr. du Temple was anxious to claim that he was the first to produce a boiler having the features he described, and was therefore, no doubt, unaware that Mr. Gurney had made a boiler for use in his steam-carriage, in which an upper and lower vessel were connected by small tubes exposed to the fire, and also by large tubes not exposed to the fire, in 1826. He was aware before he commenced his own boiler, that Mr. du Temple was making experiments with a water-tube boiler in steam-launches. He, however, was ignorant of the details; and, beyond

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the fact that he learned incidentally that one of his firm's torpedo-boats was being fitted by the French Government with a du Temple boiler, he knew nothing of the arrangement. He was not consulted in the matter, nor did he see the boiler, or learn particulars of the results. Mr. du Temple's method of connecting the small tubes with the collecting-vessels seemed to be very good, when the boiler required was so small that sufficient tubes could be thus secured in two collecting-vessels at the base; but when larger sizes were wanted, several collecting-tubes at the base became necessary, and their method of construction was less advantageous. Although the general arrangement afforded facilities for the removal of tubes, it did not appear to be favourable to economy of fuel; for it would be seen that, if the weight of the boiler were taken as a measure of its size, a useful factor could be obtained by dividing the water evaporated in an hour by the total weight of the boiler. If this factor, which was a measure of the rate of working, was multiplied by the economic result, or number of lbs. of water evaporated per lb. of coal, at the given rate of working, a number would be obtained which he would call the "weight-efficiency." Using the figures given by Mr. du Temple, and correcting approximately, the temperature of feed being unknown, for the high pressure used, the rate of working was 0·75 lb. of water evaporated per lb. of boiler, and the evaporation per lb. of coal, corrected as before, 7·0, which, multiplied by the rate of working, gave a weight-efficiency of 5·25. The same figures for the Thornycroft boiler were:—Rate of working, 0·86 lb.; evaporation, 10·29; weight-efficiency, 8·85. These figures proved that the boiler, although worked at a less rate, did not give nearly the same advantage in economy of fuel. It might be pointed out that Mr. du Temple's boiler, when compared in weight-efficiency with the boilers of the mail-steamer of which Mr. List had given particulars, appeared to very great advantage, as the weight-efficiency of the latter was only 0·95; the lbs. of steam produced per lb. of boiler and water being only about 0·09.

In the discussion and correspondence on this Paper, the Author was much gratified to find that his ideas of the value of circulation in steam-boilers had not been questioned; but he would have been glad if the discussion had been directed more to this subject, as it was the one to which he had given his best attention.

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26 November, 1889.

SIR JOHN COODE, K.C.M.G., President,
in the Chair.

The discussion on the Paper by Mr. J. I. Thornycroft, on "Water-Tube Steam-Boilers for Marine Engines," occupied the evening.

3 December, 1889.

SIR JOHN COODE, K.C.M.G., President, in the Chair.

The following Associate Members have been transferred to the class of

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Associate.

GEORGE ALFRED BARNETT, C.I.E.

The discussion on the Paper by Mr. J. I. Thornycroft, on "Water-Tube Steam-Boilers for Marine Engines," occupied the evening.

10 December, 1889.

SIR JOHN COODE, K.C.M.G., President,
in the Chair.

(*Paper No. 2407.*)

"On the Triple-Expansion Engines and Engine-Trials at the Whitworth Engineering Laboratory, Owens College, Manchester."

By PROFESSOR OSBORNE REYNOLDS, LL.D., F.R.S., M. Inst. C.E.

IN designing steam-engines to take their place amongst the appliances of an engineering laboratory, at the present stage of the development of these institutions, many considerations present themselves.

The primary purpose of the engines is to afford the students opportunities of practice in making the various measurements involved in steam-engine-trials, and to afford them an insight into the action of steam in the engine, as well as of the mechanical actions; also to render them familiar with good examples in steam-engine design.

Another purpose, however, which it is very desirable such engines should serve, is that of supplying a means of research by which knowledge of the steam-engine may be extended. A systematic and experimental investigation of the steam-engine involves two sets of conditions which, unless it be in a laboratory, can hardly exist together, namely, the time and attention of the scientific investigator, and the assistance of a considerable number of trained observers. In the engineering laboratory these conditions should exist; the first being supplied by the permanent staff, and the second by the students as their training advances.

The making and repeating of the individual observations involved in a scientific engine-trial, as well as reducing the results, demands an amount of patience and perseverance which is severe on one so young and inexperienced as a student; but the importance and reality which the research adds to all the detail of the work, as well as the complete attention and overlooking which it ensures from those responsible, constitute very great advantages.

Having regard to these two purposes, the Committee, Mr. John Ramsbottom, Mr. John Robinson and the Author, appointed by the Council of Owens College to select, amongst other appliances, the steam-engines best adapted for the special purposes of the laboratory, decided that the engines, while as far as possible representing in their principal members the most approved existing practice in steam-engine construction, should be specially designed to afford the utmost facilities for experiments on the use of steam throughout the entire range, and, if possible, beyond the limits hitherto accomplished in practice.

As best meeting this demand it was decided to have three engines working on separate brakes.[1] All engines to be of the inverted-cylinder type, with the walls and covers separately jacketed with steam at boiler-pressure, and so arranged that they could be worked with or without steam in any or all of the jackets. Each engine to work with steam at any pressure up to 200 lbs. per square inch, to run at any piston speeds up to 1,000 feet per minute, and to have expansion-gear to cut off from zero up to ⅔ of the stroke. One engine to be supplied with air-pump and surface-condenser, the other two engines to be furnished with alternative exhausts, either into the atmosphere, or into steam-jacketed receivers supplying steam to the next engine, each of the receivers also having an alternative supply of steam direct from the boiler. The boiler to be of the locomotive type, having 5 square feet of grate, to be set in a hot chamber with an economizer and alternative chimney and forced draught, on the closed stoke-hold system. The condenser to have 200 square feet of cooling surface. The dimensions of the engines to be somewhat as follow:

Engine.	Diameter of Cylinder.	Stroke.	Diameter of Crank-Shaft.
	Inches.	Inches.	Inches.
No. I (high-pressure) . . .	5	10	2¾
No. II (intermediate) . .	8	10	2¾
No. III (low-pressure) . .	12	15	4
Air-pump on No. III . . .	9	4½	
Feed-pump „	1½	2	

[1] The advantage of having the engines on separate brakes was suggested to the Author by Mr. J. I. Thornycroft, M. Inst. C.E.

In addition to the brake, each engine was to be furnished with a fly-wheel, to act as a belt or rope-pulley, weighing about 1,200 lbs., carried on a separate shaft with a coupling to the crank-shaft.

The firm of Messrs. Mather and Platt, Salford Iron Works, undertook the preparation of the designs and the construction of special engines and boiler to meet in all respects the wishes of the Committee, and spared neither trouble nor expense in carrying out the work. It was entirely owing to the zeal and liberality of this firm that the College was enabled to meet the expense of an undertaking involving so much special work.

The design of the engines, shown in Plate 4, Figs. 1 and 2, contains many novelties. These were not adopted without what appeared to the Committee to be sufficient reason, as it was unanimously desired to adhere as far as possible to ordinary types.

As regards the cylinders, pistons, and valves, there are three noticeable departures; these were adopted with a view—

1. To ensure the completeness and efficiency of the steam-jackets.

2. To diminish the resistance to the passage of steam as much as possible.

3. To keep down the clearance.

4. To obtain an adjustable cut-off from zero at any speed.

1. To obtain completeness in jacketing, both ends (or covers) were jacketed as well as the walls. To ensure efficiency of the jackets steel liners were used and the covers were domed, so that the surfaces should free themselves by gravitation from the water resulting from condensation, the water being drained from the lowest point in the jacket spaces.

2. To diminish the resistance of the passages, these were abnormally large, the area of the ports being 13 per cent. or $\frac{1}{7\cdot5}$ the area of the piston, and the steam-chests were very large.

3. To diminish clearance, the ports were made straight, and the valves brought as close as possible to the cylinder, double valves being used. The pistons were formed to occupy the space in the cylinder, except $\frac{1}{8}$ inch clearance at the ends. The result is that in engine No. I the clearance space shut in by the main valve is 4 per cent. and 1·7 per cent. more by the rider, and in engines II and III the clearances shut in by the main valve are 6 per cent. and 2·5 per cent. more by the riders.

4. To obtain an adjustable cut-off, since at the higher speed the engines were intended to run 400 revolutions per minute, it was practically impossible to use any form of trip cut-off. Meyer expansion-valves were used on the backs of the main valves.

The engines are exceptionally strong, being all of them designed to work safely with a pressure of 200 lbs. on tho square inch, so that the effect of expansion in one cylinder might be compared with compound or triple expansion.

The frames of the engines are of a somewhat novel form, and their purpose may not be immediately apparent. It will be seen, however, that the front cover is cast with a kind of entablature or box, connected with the base-plate by four wrought-iron columns placed symmetrically as regards the piston-rod. The function of these columns is to withstand the vertical forces arising from the steam-pressures on the cylinder covers, and to maintain the axis of the cylinder vertical against any forces; they are not calculated to maintain a horizontal position against lateral forces such as might arise from the action of the slide-block. To meet such lateral forces the base-plate is prolonged upwards in the form of a strong box standard, the upper portion forming the slide-bars, which at the top encircle the piston-rod and pass within, but not touching the box cast on the cylinder cover. Through the sides of this box are four horizontal set-screws, which grip the top of the standard, and so transmit any lateral force directly to the standard, as well as admitting of the adjustment necessary to maintain the cylinder co-axial with the slide-bars.

In this way the vertical forces are taken symmetrically, and cause no distortion of the engine. The cylinder is held very rigidly by the four columns, and the horizontal forces arising from the pressures of steam in the pipe, and particularly from the expansion and contraction of the pipes under a variation of temperature of more than 300°, are taken by the cast-iron standard. And, what led more than anything else to this design, all distortion arising from heat is avoided. The heat-connection between the cylinder cover at 400° is cut, except for the four columns which are heated symmetrically and the four set-pins which conduct very little heat to the slide-bars.

The result appears very satisfactory, the engines running with the slide-bars cool at 400 revolutions per minute, doing 100 HP. with great steadiness.

The somewhat peculiar general arrangement of the engines, Plate 4, Figs. 3, 4, seems to require a word of explanation. Vertical engines were adopted on account of the much greater accessibility they afford to all the parts; also because they allow of the water from the steam-jackets being drained back into the boiler with a less difference of level between the floors of the boiler-house and the engine-room.

The crank-shafts of the engines were raised 3 feet above the floor in order to allow of the floor being kept level and to admit of pulleys 5 feet in diameter; also because 3 feet is a convenient height for working the brakes, oiling and adjusting the gearing. The most noticeable feature in the arrangement of the engines—the distance between them—was necessitated by the alternative shaft connections which it was decided to give them, and particularly by the room required for the belt and rope-gearing, and for working the three separate brakes.

The complete shaft consists of seven separate shafts on separate bearings, which can be connected into a single shaft by six special coupling-boxes. The shaft immediately on the right of each engine carries a brake, and these brake-shafts of the two smaller engines carry 11-inch belt-pulleys, 5 feet in diameter, weighing 11 cwt., while the brake-shaft for the low-pressure engine carries two 15-inch pulleys, 3 feet in diameter, weighing 9 cwt., one for a belt and one for ropes. These pulleys act as fly-wheels when the engines are working separately; and, in addition to these, there is between the brake-shaft of the intermediate engine and the crank-shaft of the low-pressure engine an intermediate shaft carrying a 12-inch rope-pulley, 5 feet in diameter, weighing 12 cwt., which may be used as an auxiliary fly-wheel on this engine.

When the crank-shafts are working coupled as a single shaft at more than 200 revolutions per minute these larger wheels must be removed from the shafts.

A first-motion shaft, 16 feet distant and 12 feet high, carries pulleys 3 feet in diameter corresponding to those on the engine-shafts, so that the engines can be geared conjointly or separately on to the first-motion, and this again geared on to one of the brakes, by which means the efficiency of the gearing may well be tested.

The coupling-boxes, Plate 4, Figs. 7 and 8, on the main shaft are intended to serve two purposes. (1) To afford a ready means of connecting or disconnecting the several shafts. (2) To allow of any side-play which may arise from the proximity and number of the bearings.

To serve these purposes it was necessary to have a special flexible coupling, which led to the design of a modified form of Oldham's coupling, with an intermediate disk, to which the flanges on the shafts are separately connected, each with two parallel drag-links at equal distances on each side of the shaft. The drag-links, which connect one shaft with the disk, being at right-angles to those which connect the disk to the other shaft, so that the shafts

are perfectly free to play laterally. The links are held by pins screwed into the flanges and disk. To disconnect the shafts all that is necessary is to remove four of these screws and the two links they hold, which leaves the shafts free with a considerable interval between them. These couplings, while very flexible, transmit a perfectly uniform motion and throw no forces on to the bearings.

The intervals between the engines necessitated by this intermediate gearing are 7 feet between No. I and No. II, and 12 feet between No. II and No. III. These intervals entail no evils in the working of the shaft except the increased friction arising from the additional weight and number of the bearings. This friction may be accurately measured and taken into account in determining the brake HP.

The Arrangement of the Intermediate Steam-Connections, Plate 4, Figs. 3 and 4.—This was adopted in order—

(1.) To allow of the engines—

Nos. I, II and III	being	worked	as a	triple-expansion condensing engine.
„ II and III	being	worked	as a	compound condensing engine.
„ I and II	„	„	„	non-condensing engine.
„ III	„	„		single condensing engine.
„ I or II	„	„	„	non-condensing engine.

(2.) To secure that the steam-supply to each engine, under whatever circumstances it might be working, should be dry without intermediate drainage, so that the weight of water discharged by the air-pump might measure the steam admitted to each engine as steam.

(3.) To bridge over the intervals between the engines without allowing the changes of temperature to cause undue stresses in the pipes and the supports of the engines.

The exhaust-passages from No. I and No. II engines are closed respectively by a 4-inch and a 6-inch steam-valve, while an alternative exhaust-passage, which may be connected directly with an exhaust-pipe in the floor or closed by a blank flange, is provided. The steam-valves in the exhaust-passages open into receivers which supply steam to No. II and No. III engines respectively, which receivers also have alternative connections with the main steam-pipe, so that each engine can have a separate steam-supply.

The jacketed receivers, which are the intermediate steam-passages between the engines, are cast-iron pipes 6 and 8 feet long respectively, lined with wrought-iron pipes 4 inches and 6 inches

in diameter, the space between the pipe and casting constituting the space for the steam at boiler-pressure. These receiver-pipes are connected with the engines which they supply by S copper pipes of 4 inches and 6 inches diameter respectively, the copper pipes serving as expansion-joints; the expansion in the 12-foot interval between No. II and No. III engines amounting, with 200 lbs. of steam in the jackets, to 0·25 inch.

The arrangement of the steam-pipe which supplies the receivers was adopted in order that the steam might be dry. This pipe leads from a water-separator, as a 2½-inch pipe which enters a jacketed receiver No. I, 4 feet long lined with a 2½-inch wrought-iron pipe, to prevent condensation of the steam after leaving the separator. The receiver leads to a point near No. I engine, and is connected with a casting in which are two steam-valves opening into 2-inch copper pipes which lead to the steam-chest of No. I and the receiver between No. I and No. II. The other end of the receiver is connected through a steam-valve with the receiver between No. II and No. III. In this way, whichever engine is receiving steam from the boiler, the steam has to traverse a steam-jacketed receiver.

The positions of the boiler and engines, Plate 4, Fig. 5, was adopted to allow not only of the water from the jackets on the cylinders, steam-chests, and receivers draining back into the boiler, but also to allow of its doing so when the pressure of the steam in the separator was 3 lbs. per square inch below that in the boiler.

To ensure this, the level of the water in the boiler is kept 6 feet below the lowest jacket to be drained. The boiler-house, which is separated by a glass partition from the engine-room, has a floor 5 feet below the engine-room, and the level of water in the boiler is 1 foot above the engine-room floor, the boiler being 20 feet distant horizontally from the engines.

The steam-pipe, 2½ inches in diameter, takes the steam from the top of the dome on the boiler and enters the engine-room 2½ feet above the floor; immediately in the engine-room is a steam-valve; 2 feet from the wall the pipe rises vertically 8 feet, then turns horizontally for 10 feet, and then again turns down vertically until it enters the separator. At a height of 10 feet there is a branch 2 inches in diameter, without a valve, which supplies all the jackets with steam at the pressure of the boiler less the resistance of the pipe, which is always less than ½ lb. on the square inch. The main pipe then enters the water-separator through a reducing-valve which lowers the pressure 2 lbs.; below this reducing-valve is the steam-pipe leading to the receivers, and below this again the steam-

drain from the jackets enters the separator, and 3 feet below this the water drains from the jackets. The separator now descends as a vertical pipe 1½ inch in diameter to the floor, and then proceeds horizontally until it joins the feed-pipe from the economizer just before entering the boiler, having a back valve and a stop-valve, and also a blow-off valve.

The separator for 3 feet at its upper end consists of a vertical cast-iron cylinder 6 inches in diameter; it is then reduced to a 1½ inch pipe. Communicating with the separator at its top, and at a point 1 foot from the engine-room floor, is a water-gauge of ordinary construction except that the tube is 6 feet long. This gauge shows the level of the water in the separator. When the engines are standing with the blow-off shut, the water remains at the bottom of the gauge. Any water from the jackets drains back into the boiler. If the blow-off is opened the pressure in the separator falls and the water rises to balance the excess of pressure in the boiler, which is shown by the water-gauge; steam is drawn through the jackets as it cannot pass the reducing-valve until the pressure has fallen 2 lbs. below that in the boiler; in this way the engines are heated.

When the engines are running they draw steam out of the separator below the reducing-valve, and hence all the steam is drawn through the jackets until the resistance in the passages reaches 2 lbs. on the square inch; the water in the gauge shows the level at which it stands in the separator. When the pressure in the separator is 2 lbs. below that of the boiler, the water in the separator stands about 5 feet above the floor, which is just the bottom of the 6-inch cylinder; the water then as it enters the separator gravitates to the boiler. If, however, the stop-valve at the bottom of the separator is closed, the water is collected in the 6-inch cylinder, and, as its level is shown on the gauge, this furnishes a ready means of measuring the condensation from jackets and radiation, which measurements may be checked by draining off the water through the blow-off.

In this way the total condensation from jackets and radiation is determined, and, on consideration, it will appear that herein is an exact measure of all the heat supplied from the boiler over and above that which leaves the engines as steam. It will also be seen that the separator ensures complete water drainage of the jackets and a draught of steam through the jackets and jacket-pipes.

The arrangement of jacket-pipes and drains, which is very complex, was necessary in order that the walls, back and front

covers, steam-chest covers, and receiver-covers for each engine might be separately jacketed, and drained both of steam and water. In all there are fifteen separate jackets.

To ensure an equal passage of steam through all these jackets, it would have been desirable, had it been practicable, to supply them in series, so that the steam should pass from one to the other; but this, for obvious reasons, was impracticable, and it was necessary to so arrange the pipes that the head of steam to cause circulation through each jacket should be nearly equal.

This is accomplished by carrying the distributing-pipe, $1\frac{1}{2}$ inch in diameter, throughout the entire length of the engines, as high as practicable. Also the steam-collecting drain, $1\frac{1}{2}$ inch in diameter, and the water-collecting drain, 1 inch in diameter, and arranging them so that there might be a fall all the way in the direction in which the steam was moving. A branch from the steam-pipe with a valve supplies each receiver-jacket on the top, and a drain from the bottom of each receiver-jacket branches into two, one branch falling to the water-drain, and the other rising to the steam-drain, these branches being $\frac{3}{4}$ inch and $\frac{1}{2}$ inch in diameter.

Each engine has a branch from the distributing-pipe and from each of the drains, which can be closed by valves. The branches from the two drains unite into one drain before branching to the jackets. Then from the distributing branch on each engine are four branches leading respectively to the four jackets on the engines, and in the same way four drains from the four jackets unite in the one branch from the drain. The jacket-pipes are of copper with iron screwed joints, except the unions, valves, and flanged-joints to the covers, which are of brass. The system is extremely complex, but nothing short of this would suffice for the special purpose of these engines. There are twelve steam-valves, thirty flange connections, and more than forty unions, and about one hundred elbows, tees, and running-joints. The use of running-joints was a mistake; they were adopted for simplification, but they should have been unions, it being found very difficult to make the back nuts stand. They were first tried with red-lead and hemp in the ordinary way; this stood a pressure of 200 lbs. per square inch for about two days. The couplings were then faced, and nothing but a little putty was used, but these failed. Then another method was tried which has answered well, and the whole system has been working practically tight.

The Covering of Cylinders, &c.—The temperature of the steam-jackets, about 400° Fahrenheit, rendered the covering of the steam-pipes and cylinders a matter of first importance, not only to prevent

loss of heat by radiation, but to render it possible to operate near the engines. In the first instance, the cylinders and receivers were surrounded with 2 inches of glass-wool, and lagged with 2 inches of baywood, but the glass-wool, being found to create gritty dust, was removed, and an inner lagging of soft pine substituted for it. The steam-chest covers and the water-separator were also lagged in the same way; while all the steam-pipes, except the copper expansion-pipes and jacket-pipes, which could not be brought under cover of the wood lagging, have been covered with 2 inches of asbestos cement.

The surface-condenser is of the torpedo-boat type of thin copper, 14 inches in diameter, and 4 feet long. It has about 160 square feet of heating-surface, and receives the steam by an 8-inch exhaust-pipe from the 12-inch engine.

The air-pump, working by side-levers from the slide-block of the 12-inch engine, is 9 inches in diameter, with a 4½-inch stroke, with foot-valve, piston-valve, and cover-valve, and is designed to work up to 400 revolutions per minute.

The condenser and air-pump are conveniently placed on a bracket on the standard of the 12-inch engine, which also forms a stage for indicating the engine. This stage is 5 feet from the floor, which gives sufficient but not too much room for conveniently measuring the water from the hot-well and the condensing water.

The Feed-pump.—This was adopted in order to maintain a regular feed in the boiler, as well as to enable the water from the hot-well to be returned to the boiler. It is worked from the rocking-shaft of the air-pump levers; it has a plunger 1½ inch in diameter with a 2-inch stroke, and draws water from a feed-tank 3 feet below it, discharging into a feed-pipe, which, together with the economizer or water-heater, leads through 70 feet of 1¼-inch pipe to the boiler. The inertia of this column of water becomes very considerable when the speed is as great as 400 revolutions per minute, and this, together with the 200 lbs. pressure, seemed to render it doubtful whether the pump would answer. However, by means of a special device, a cushion of air or steam was provided about 4 feet from the pump, and by another device the pump was made to start itself, notwithstanding the 3 feet draw, so that the pump works silently and without trouble up to 400 revolutions.

The Governors.—For the special investigations into the action of steam, governors were unnecessary. The load on the engines being constant, the cut-offs fixed, and the supply of steam regular, small variations of speed would be of no moment; while any alteration of the pressures of steam or cut-off by the governors

would only confuse the trials; besides which, the problem of governing engines working in conjunction as regards steam, but on separate brakes, was altogether a new one. At the same time, as a matter of safety, the complexity of the system, the number and inexperience of the observers engaged at any time on the engines, the extreme circumstances as regards steam-pressure and speed under which the engines were designed to work, rendered it imperative that the engines should be so far governed, that under no circumstances could the speeds exceed a safe limit, which, with the 5-foot cast-iron fly-wheels on the shafts, would be about 600 revolutions per minute.

To meet both these considerations, what seemed to be necessary was a safety-governor, which, while it would interfere in no way with the passage of steam at speeds below the limit, would with the utmost certainty cut off steam at some definite speed before the limit was reached.

To ensure certainty of action, it was necessary that the governor should be permanently geared to the engine, and not merely engaged by a belt. And to secure rapidity of action when once the limit of speed was reached, it was desirable that there should be as little room as possible for steam between the governing-valve and the piston; in other words, that the governor should close the expansion-valve.

The Meyer expansion-valves, which had been selected as peculiarly suitable for the purposes of these engines, actuated as they are by screws of such moderate pitch that it requires five or six turns to close the valves, are not susceptible of being opened and closed by the direct force of governor-balls. It therefore became necessary to adopt some form of engagement-governor which, instead of acting on the valve, should act on a clutch which engaged the crank-shaft of the engine with the valve-spindle when the limit of speed was reached. The clutch here adopted is the Author's spiral steel band-clutch. This clutch, which requires almost an insensible force to engage it, is absolutely certain in its hold.

In order to operate on the valve-spindle it was necessary to use two pair of bevel-wheels, which could not be made less than 4 inches and 6 inches in diameter. To throw this train of wheels suddenly into gear with a shaft making 400 revolutions per minute seemed a doubtful proceeding, but such is the softness of action of the clutch, although there is no slipping, that there is neither noise nor shock. The engagement is silent and instantaneous, so that unless special attention is directed to it the movement of the 10-inch hand-wheel will probably escape notice. The clutch is

as good in disengagement as in engagement, and will release the shaft before it has turned more than 5° or 10°.

Although the main object of these governors was that of a safety-governor, opportunity was taken to so design them that they should, if required, open the valve as the speed fell, as well as close it as it rose, arrangements being made to prevent hunting. The governors so obtained are extremely efficient, and afford an excellent means of studying the action of governors. During the steam trials, however, they are simply set to act as safety-governors, which they have done to perfection, never having been out of action, or having allowed the speed of the engine to exceed the limit to which they are set.

The boiler (Plate 4, Figs. 5 and 6) is of the locomotive type with iron tubes and firebox, the shell being of steel $\frac{9}{16}$ inch thick. The tubes are 2 inches in external diameter and 8 feet long, giving 160 square feet of tube surface. The firebox is $\frac{8}{16}$ inch thick, 2 feet 3 inches by 2 feet 4 inches, 4 feet high, giving 42 square feet of heating-surface.

The area of the grate as used is not more than 4 square feet.

The boiler is furnished with a dome, from the top of which the steam-pipe descends and passes out at the side.

The feed enters the boiler just below the water-level and in front of the firebox.

There is an iron smoke-box at the end of the boiler from which there are several passages for the gases. The usual passage is beneath the barrel of the boiler, 3 feet broad and 6 inches deep, and about 6 feet long, proceeding at a slight inclination downwards towards the firebox; across this passage the feed-pipe ranges backwards and forwards, and a series of scrapers are worked to keep the pipes clean. The pipes cross forty times, and give about 50 square feet of heating-surface, 40 square feet of which is kept clean by the scrapers. In this arrangement the water ascends in the opposite direction to that in which the gases descend. The gases, after emerging from the water-heater, descend into a flue leading to the chimney, which is 100 feet high, and takes the gases from other furnaces, affording generally about $\frac{3}{8}$ inch draught.

The boiler and water-heater are enclosed in a brick chamber arched over. This chamber is 6 feet wide and 9 feet high, extending from the front of the firebox to the end of the smoke-box.

At the firebox end a second chamber is built 6 feet by 6 feet and 8 feet high. This, by shutting a door, becomes a closed stoke-

hold, into which a fan can be used to force air at any pressure up to 2 inches of water.

In this chamber is an injector, a feed-tank, and water-supply, a window looking at the safety-valves, and a window into the engine-room, also a tumbling-hopper for admitting coal.

There are two 1-inch dead-weight safety-valves on the boiler, loaded to 200 lbs. on Schaffer and Budenberg's gauges, *i.e.*, 400 inches of mercury, as well as the usual fittings.

The Measuring Appliances.

These, in respect of the brake-dynamometers, the indicating gear, the gauge for jacket-water, and the tumbling-bay and tank for the condensing water, are of a permanent character. Provision is also made for measuring the temperature of the gases in the smoke-box as they emerge from the tubes, and in the flue as they leave the water-heater, and for measuring the temperature of the feed before passing the pump, and as it enters the boiler after passing the water-heater.

The condensing water is drawn from an iron tank 20 feet by 10 feet by 10 feet, about 116 feet above the engine-room floor. A permanent mercurial gauge in the engine-room always shows the level of water in this tank. The great head, although, of course, a waste of power, is of advantage in securing regularity of flow. The water after leaving the condenser enters a cast-iron tank, 4 feet by 18 inches by 18 inches, from which it issues over a tumbling-bay 4 inches wide; in the tank are bafflers and a float, with a scale graduated to show in lbs. per minute the quantity running over the bay. The water is then caught in a second receiving tank and conducted to an underground concrete tank 20 feet by 9 feet by 11 feet, the level of water in which is shown in the engine-room by a water-gauge, and also indicated outside by a float. This tank, which has been accurately measured, affords a very exact means of checking the indications of the float in the tumbling-bay.

The upper tank holds 12,000 gallons of water, which can be passed through the condenser before the tank is empty. When the upper tank is empty, if more water is required the quadruple centrifugal pump is set in motion, which raises the water at the rate of 10,000 gallons an hour from the lower to the upper tank; but it is seldom necessary to resort to this. The temperature of the condensing water is measured by a thermometer in the pipe

leading to the condenser, and after leaving the condenser by a thermometer in the float-tank.

The water from the hot-well flows into an oil-separating tank, from which it overflows on opening a cock, and is caught in a 100-lb. tip-can after Mr. Bryan Donkin's pattern, from which it may be tipped into the feed-tank, so that the feed and hot-well discharge is measured at one operation.

The condenser is furnished with a mercurial gauge, which shows the absolute pressure in the condenser; also by a Bourdon vacuum-gauge, and the temperature of the discharge from the hot-well is measured by a thermometer in the hot-well. The water, resulting from radiation and jacket condensation, is measured in the water-separator.

The pressures in the receivers are shown by Bourdon gauges, graduated to lbs., which, on the authority of Messrs. Schaffer and Budenberg, means 2 inches of mercury—a fact which it is important to know in comparing these pressures with the indicated pressures.

Each engine is provided with a counter for recording the revolutions.

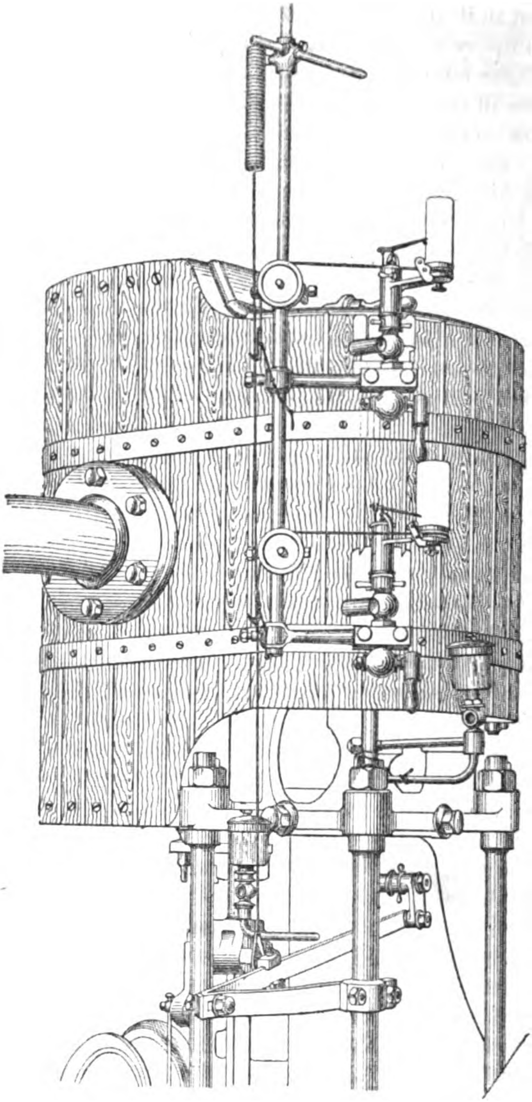
The Indicating Gear (Fig. 1).—The indicator cocks have a clear ½-inch way into the cylinder, the cock being placed at the end of a stiff brass tube screwed horizontally into the cylinder, and reaching through the 4 inches of lagging. The cock itself forms an elbow, to allow the indicator to have a vertical position.

The cocks from the back, and from the front of each cylinder are in the same vertical line, so that the indicators stand vertically over each other in a convenient position to receive the motion for the drums. This is obtained, in the 12-inch engine from the air-pump levers, and in the other engines from levers specially connected by a link with the slide-blocks.

In all cases the indicators are some feet above the levers, and while the motion of the levers is vertical, that of the drums is horizontal. The connection of the drum with the lever could be made by a simple cord or wire passing over the roller on the indicator drum down to the lever; but considering that the chief function of the engines was to be regularly indicated, and this by inexperienced hands, and that the speeds would sometimes be such that the ordinary method of hooking up would be impracticable, some more convenient and permanent arrangement seemed desirable. The Author was thus led to a device which, from its simplicity and convenience, particularly in the matter of hooking up, as well as its effect in diminishing errors arising from the

stiffness and stretching of the cord, seems likely to be generally useful.

Fig. 1.



This method consists of a $\frac{3}{8}$-inch pin in the side of the lever with a head, a light brass plate $\frac{1}{2}$ inch thick, with a button-hole to

permit its passing over the head of the pin, and, when pulled up against the pin, allowing of considerable wear. To this brass is attached a steel wire 19 B.W.G., long enough to reach beyond the furthest indicator, that on the back of the cylinder, the wire being held up by a spiral wire spring of such length and stiffness that it will stretch 6 inches under a force of 25 lbs. without causing undue stress in the wire.

The wire connecting the lever with the spring passes the indicators, and is furnished in convenient positions with two buttons for hooking on the cords of each of the indicators. This is effected by having a light forked hook attached to the end of the cord, which has only to be pulled beyond the button, and one limb of the fork placed on each side of the wire and then let go, when the spring of the drum pulls the hook up against the button. Thus hooking up can be accomplished with facility and certainty at whatever speed the indicator is running. The length of the cord is reduced to a minimum at both ends of the cylinder.

In these engines, where the pistons of the indicators have a motion parallel to that of the pistons of the engines, the cord has to turn a right-angle between the drum and the hook. This might be effected by the rollers on the indicator; but as they are usually very small and not adapted for wear, two clips are made to pinch on to the indicator cocks on the cylinder. The clips have circular sockets in line with the motion of the piston of the engine with a set-screw; through these passes a ½-inch steel rod, long enough to carry an adjustable arm to hold the end of the spring, and two adjustable rollers 2 inches in diameter for the cords to pass over.

The Hydraulic Brake Dynamometers (Plate 4, Figs. 9 to 13).—These are a very important feature of the system. They are the result of a special investigation as to the possibilities afforded by hydraulic brakes, undertaken by the Author during the time when the engines were under the consideration of the Committee and before anything was decided.

Having had a great deal of experience with almost every conceivable form of friction brake, the Author had arrived at the conclusion that, although it is possible to construct such brakes to work with almost any degree of accuracy, certain inconveniences and drawbacks attend their use, which in all cases leave much to be desired, particularly where, as in a case like this, work on the brake is the sole object of the engines.

(1.) Such brakes require constant observation and watching.

(2.) A single engine cannot be started without relieving the load.

(3.) Such brakes are cumbersome and are not easily adapted to measure greatly different powers.

(4.) Any particular brake cannot without considerable pulling about, such as altogether removing the brake and brake-wheel, be rendered altogether nugatory. It was desirable :—

1. That the brakes should be certain in their action without any attention while the engines were running.

2. That they should leave the engines free to start, and then take up their load without attention.

3. That they should be put on and off by a simple operation.

4. That when turned off they should offer no sensible resistance to the engines.

5. That they should be capable of being so adjusted as to impose any particular resistance, from zero to the greatest, at any speed at which it was desired to run the engines.

6. That the resistance of the brake, when once adjusted, should be independent of the speed of the engine.

7. That the necessary size and structure of the brakes should not be such as to incommode or hamper the engines.

8. That the resistance of the brake should admit of absolute determination from a single observation.

Of these attributes 1 and 2 belong to all fluid resistance, such as that of the screws of steam-ships or centrifugal pumps, in which cases the resistance, varying as the square of the speed, is zero when the engines start.

If the casing of a centrifugal pump, or the tank in which a paddle or screw works, be suspended on the crank-shaft, making a complete balance when the shaft is at rest, then, when the shaft is in motion, the moment of resistance on the shaft will be exactly equal to the moment to turn the casing round the shaft. This can be readily and absolutely measured by suspending weights at a definite horizontal distance from the shaft. The first published account of this form of brake having been made use of for dynamometric measurement was by Hirn,[1] in his investigation for the verification of Joule's mechanical equivalent of heat, and was subsequently adopted by Joule in his second determination.

In neither of these cases, to the Author's knowledge, was there any attempt to vary the resistance at a constant speed.

Having occasion to use a dynamometer for measuring the resistance on the shaft of a multiple steam-turbine at speeds of 12,000 revolutions per minute, which was engaging his attention in 1876,

[1] Théorie Mécanique de la Chaleur, 2nd edition, 1865, p. 55.

the Author made use of a brake, having a centrifugal pump suspended on the shaft and working into itself. The resistance, or head against which the pump was working, was regulated by a valve between the exit and inlet passages, that is, in the external circuit made by the water. This was brought before the Mechanical Section of the British Association in 1877. At the same meeting, Mr. William Froude gave an account of his hydraulic brake, for measuring the power of large engines, in which the resistance was regulated on the same principle as that adopted by the Author, namely, by adjusting diaphragms or sluices in the passages between the revolving wheel and the casing. In other respects Mr. Froude's brake differed essentially from any of those previously used, being designed to obtain a maximum resistance with a given sized wheel. For this purpose Mr. Froude invented an internal arrangement which affords a resistance out of all comparison with any other form.

Since great resistance, admitting of small brakes, was of extreme importance for these engines, the first step in the special investigation was the construction of a model Froude's brake with a 4-inch wheel; the object of which was to ascertain how far the sluices would act in maintaining a constant resistance at any particular speed, and what was the minimum resistance when the sluices were closed.

With this brake it was found that the minimum resistance was about 0·08 of the maximum; a hardly satisfactory range, considering it was desired to run the engines at a constant load at from 100 to 400 revolutions per minute, the maximum resistance of the brake ranging from 1 to 16, so that the minimum at 400 would be 26 per cent. greater than the maximum at 100 revolutions, apart from the fact that closing the sluices would not render the brake nugatory.

This, however, was of small importance compared with another fact revealed by these experiments. When the speed of the brake-wheel exceeded a certain small limit, determined by the head of water under which it was working, the maximum resistance gradually fell off in a surprising and somewhat irregular manner. This falling off was found to be owing to the brake partially emptying itself of water, due to the air from the water gradually accumulating in the centre of the vortex—a fact which, if not dealt with, threatened to render such brakes useless for the purpose of these engines.

The argument was simple: in a vortex the pressure at the centre is less than the pressure at the outside. The pressure at the outside in these brakes is determined by the atmosphere,

and the small head under which they are working; and the outside forms a closed surface. The pressure at the centre will therefore, at different speeds, fall below the pressure of the atmosphere. Air will be drawn from the water and accumulated in the centre, occupying the space of the water and diminishing the resistance; and, owing to various causes, the action will be irregular. This would be prevented if passages could be carried through the outside to the axis of the vortex, carrying a supply of water at or above the pressure of the atmosphere, so to prevent the pressure at this point falling below that of the atmosphere. This was accomplished by perforating the vanes of the wheel, and supplying water through the perforations. It also appeared that, by having similar perforations in the casing open to the atmosphere, the pressure at the centre of the vortex could be rendered constant, whatever the supply of water and speed of the wheel; so that it would then be possible to run the brake partially full, and regulate the resistance, from nothing to the maximum, without the sluices. These conclusions having been verified on a model, it was decided to arrange the engines with the shafts in line, with three brakes on the shafts; and the brakes, with 18-inch wheels, were designed according to the resistance given by the model. The brakes promised all the attributes desirable, except that of running with a constant load under varying speeds. This matter was considered during their construction, and an automatic arrangement was devised acting on cocks regulating the supply and exit of the water to and from the brake necessary to keep it cool, the lifting of the lever opening the exit and closing the supply, so as to diminish the quantity in the brake, and *vice versâ*.

The danger of such an arrangement hunting was carefully considered, and precautions were taken. The brakes were constructed by Messrs. Mather and Platt at the same time with the engines, and the engines started with the brakes and automatic gear complete. During the twelve months they have been running the brakes have demanded and received no attention whatever. They are easily tested for balance. They have neither fixed nor spring attachment, except the bearing on the shaft. They are loaded on a 4-foot lever, with 2-inch play between the stops. When the speed of the engines reaches about 20 revolutions per minute, the levers rise (whatever load they have on), and, though always in slight motion, they do not vary $\frac{1}{2}$ inch until the engines stop; during the run the load on the brakes may be altered at will, without any other adjustment.

The Engine-Trials.

Before commencing the trials, the object to which they were to be directed, and the manner in which they should be conducted, were carefully considered, and it was decided:—

1. That the purpose of the trials should be the elucidation of the general laws of the action of steam in the steam-engine, and the more general circumstances on which these laws depend.

2. That, from the commencement, the trials should be systematic; certain definite conditions being aimed at, and the trials under each set of conditions continued until consistent results should be obtained, showing how far the conditions had been achieved.

3. That there should be no casual nor unrecorded trials, but that all trials should be considered of the same degree of importance.

4. That observations should be noted and reduced on special forms according to a definite system, to be carefully preserved for future reference; and that a synopsis of the mean results of each trial should be entered forthwith in a special record for ready comparison.

The trials have all so far been conducted as part of the regular work of the laboratory, under the superintendence of the Author, Mr. Foster (assistant in the laboratory) having general charge of the appliances, and the fireman (Mr. Joseph Hall) firing and driving the engines. The detailed observations were taken and reduced by students (about fourteen on each trial) under the supervision of Mr. Mackinnon, demonstrator of the laboratory.

Diagrams are taken every half-hour simultaneously from the six ends by six students, who have charge of their respective indicators for the trial. The same students also reduce the diagrams in the intervals. The three counters are read every ten minutes by three students, who have respectively charge of the counters and running of the three engines, calculating the brake HP. as the trial proceeds, and noting any circumstance connected with the resistance or running of the engine.

One student has charge of the 100-lb. tip-can, which measures the water from the hot-well; and another has charge of the condensing water, noting the temperature and quantity given by the float every ten minutes. Another student measures the rate of discharge from the jackets every half-hour. A student watches the coal-weighing and firing. A student takes the temperatures of the hot-well and feed before and after passing the economizer, and the temperature of the air in the smoke-box and flue before and after passing the economizer. Each student reduces his observations as

he proceeds, so that within a few minutes of the end of the trial the reduction is completed.

The results are then examined by Mr. Mackinnon, checked and entered in the permanent record, the original diagrams and notes of each trial being carefully preserved.

Two series of trials have been conducted, the one by regular students between 9.30 A.M. and 5.30 P.M. The other by evening students between 6.30 P.M. and 9 P.M., one of each series being made every week.

In the day trials the fire is lighted the first thing in the morning, and steam is got up quietly. As the steam rises it is blown freely through the jackets to heat the engines. If the trial is to be made with jackets, the blowing through all the jackets is continued until the boiler-pressure reaches 200 lbs. on the gauges. Should the trial be without jackets, the jacket-covers on the low-pressure engine are closed when the pressure has reached about 40 lbs., and the air-cock is opened; those on the intermediate cylinder when the pressure reaches about 80 lbs., and those on the high-pressure cylinder at 200 lbs. In all cases the engines are started, and are allowed to run just as required for the trial for one hour. The engines are then stopped fifteen minutes before the trial, the fire is drawn, and the readings of the counters and level of the water in the boiler and tanks are taken; 14 lbs. of wood and 14 lbs. of coal are allowed for the waste of relighting, starting, and stopping. The run then commences; the coal is weighed out in charges of 100 lbs., each charge being shot from the scale-pan into the hopper in the firing-chamber, and completely consumed before the next weighing is admitted.

The boiler is fed continuously by the feed-pump, either from the water from the hot-well or, in some trials, from the water from the condenser. The runs have generally been for six hours, except when forced draught is used, in which case they last about four hours.

After the last coal has been put upon the fire, the engines are run as long as steam can be kept up, care being taken to bring the level of the water in the boiler at stopping exactly to that at starting, any difference being allowed for as 15 lbs. for each $\frac{1}{10}$ inch.

The ashes which fall through the bars are burned during the trial, and the ashes after the trial are generally weighed, but no account is taken of them, nor of any fuel that may be left in the grate.

This mode was adopted, after trying several systems, as being workable and very definite; nor does it appear, on comparing the

results from the long with those of the short trials, that the one has any sensible advantage over the other. During the experiment the regulator is fully open, and a definite quantity of water run through the condenser. The engines, therefore, take all the steam the boilers will produce, the load on the brakes just balancing the pressure of steam, so that the speed is regulated by the rate at which steam is made in the boiler, that is, by the draught-gauge. As it was intended that the scope of these trials should include as far as possible all conditions under which steam may be used, there was no particular reason for commencing with one set of conditions rather than another, except such as arose from convenience, and out of consideration for the engines themselves. The fact that the engines were new, and wanted running to bring the bearings into order, as well as the number of students to be employed, led to the first series of trials being made with triple expansion and full pressures of steam.

The Results of the Trials.

The trials commenced in March 1888, and were continued at the rate of two a week till June; in all twenty trials were made and recorded, the engines being then complete with the exception of lagging.

These early trials with 200 lbs. pressure triple expansion, with and without steam-jackets, and various degrees of expansion, gave very definite results. But they also revealed the fact that the linings of the cylinders leaked at pressures above 170 lbs. per square inch, and that the joints in the jacket-pipes could not be made to hold. They also showed that, notwithstanding the precautions taken, the jackets were liable to fall off in efficiency. The effect of the leaks was not great on the general economy of the engines, and might easily have passed unnoticed but for the rigour of the tests to which they were subjected.

At 250 revolutions per minute the thermal efficiency of the engine with jackets was—

$$\frac{\text{Heat equivalent of indicated work per minute}}{\text{Heat discharged} + \text{heat equivalent of indicated work}} = 0 \cdot 175$$

$$\text{Coal per HP. per hour} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad = 1 \cdot 48 \text{ lb.}$$

The leaks, however, tended to confuse the diagrams, and opportunity was taken of the long vacation, during which the trials were discontinued, to reset the linings of the cylinders. The lagging of the engines was completed as far as it was thought desirable.

The trials were continued in October, when the linings proved to be perfectly tight, and although at first the jacket-pipes leaked occasionally, the leakage was not of any sensible magnitude. The jackets were, however, still found liable to fall off in effect at low speeds. The trial with jackets was therefore repeated many times, small alterations being made in the jacket-pipes, until consistent results were obtained with speeds of 250 revolutions per minute, giving thermal efficiency, calculated as before, 0·20, coal per indicated HP., 1·33 lb. Corresponding trials without the jackets were then made, followed by trials at higher and lower speeds with and without the jackets. These furnish a complete series of trials of triple-expansion engines working with about 200 lbs. boiler pressure, at piston speeds from 250 to 1,000 feet per minute.

Appendix, Table I, shows the mean results as recorded for three trials at different speeds with and without jackets. Only one trial at each speed is given, though several trials have been recorded, the results not differing by 1 per cent.

Lines 4 to 29 contain the mean results from the engines.
„ 30 to 42 „ the heat discharged from the engines.
„ 43 to 48 „ „ received by the engines.
„ 49 to 59 „ „ received from the furnace.
„ 60 to 76 „ the general relations between the coal, heat, water and power.

It will be noticed that the three engines do not run at the same speed in the same trial. This is a matter of great importance, and shows the advantage of having for such trials as these the engines working on separate brakes.

The cut-off in each cylinder regulates the fall of pressure in that cylinder, but the pressure in the receiver into which it discharges is determined so as to equalize the steam received, and the steam drains off into the next engine.

If, then, the shafts are coupled, there can be only one ratio of expansion, which will make the terminal pressures in the cylinders correspond with the pressures in the receivers. But when the shafts are free the engines adjust themselves so that they pass the same quantity of steam, and the cut-offs are easily arranged to bring the terminal pressure into accordance with the pressure in the receivers. Thus, with these three separate engines, the full economic advantage of all degrees of expansion can be obtained. To do this with coupled engines would require a different ratio of cylinder volumes for each degree of expansion, these trials showing

distinctly what should be the cylinder volume for each degree with coupled engines.

The Checking of the Results.—The system rendered possible by the use of a surface-condenser, of accurately measuring the water which has passed through the engines, as well as the heat discharged from the condenser, and the feed-water, gives a certainty to the results of the trials not otherwise to be obtained. There will be always a loss between the water supplied to the feed-pump and that received by the engines; hence, unless the loss is definitely known, the actual water received by the engines can only be surmised.

In the first forty of these trials the water discharged from the engines after being measured has been returned to the boiler, the deficiency being carefully ascertained; and in no case where this has been done has the deficiency amounted to less than ½ lb. per minute, although there were no visible or perceivable leaks of any sort from joints or glands, and the boiler, when tested before and after the experiment with water-pressure, has shown no leak. Great pains have been taken to find where this water went, but without success, though it certainly did not go through the engines.

The importance of this point in determining the action of steam in the cylinder is fundamental. It is only by knowing the quantity of water passing through the engines that it is possible to compare the actual diagrams with a theoretical diagram; and the difference between the feed and the hot-well discharge would in these engines generally amount to from 5 to 10 per cent., and would vitiate any such comparison. As it is, all comparisons have been made from the water discharged from the hot-well.

Since each lb. of dry saturated steam condensed would give up about 1,000 thermal units to the condensing water, the measures of water from the hot-well and heat from the condenser keep a useful running check upon each other. It is found that the heat measured (in 1,000 thermal units) is about 4 per cent. greater than the water measured in lbs. when the jackets are on, and from 1 to 2 per cent. less when the jackets are off.

An exact calculation, as to the heat discharged per lb. of water, must involve certain assumptions, of the accuracy of which a careful comparison with the measured heat affords a valuable test. Such a comparison is shown in Appendix, Table II.

For the trials with the jackets on, the calculations are made on the assumption that the steam is released as dry saturated steam, and carries with it into the condenser the heat of evaporation at

release pressure from the temperature of the hot-well, less the external work of evaporation and plus the work done by the piston in discharging the exhaust. This expressed in quantities from Professor Rankine's Table is

$$\frac{H_2 - h_3 - (P_2 - P_3)\,V_2}{772}$$

In this calculation no account is taken of the additional heat received by the steam during its passage from the cylinder into the condenser from the hot walls of the passages.

For the trials without jackets, the calculations are made on the assumption that the steam is admitted into the low-pressure cylinder as dry saturated steam, carrying into the cylinder the total heat of evaporation from the temperature of the condenser at the temperature of admission, and that it carries this heat, less the heat equivalent of the indicated work done in this cylinder per lb. of steam, into the condenser, which, expressed in Professor Rankine's quantities, is—

$$\frac{H_1 - h_3}{772} - \frac{(\text{I.HP.}) \times 42 \cdot 7}{\text{lbs. per minute from the hot-well.}}$$

This calculation, therefore, takes no account of the heat that must be lost by the steam in supplying the heat to be radiated from the exterior of the cylinder.

Since important actions are not taken into account in these calculations, the resulting quantities cannot be considered an absolute check upon the observed quantities; they constitute, however, a valuable relative check. Thus in Trials 44, 33, 56 (with jackets) the observed discharges of heat are greater than the calculated by amounts which diminish slightly as the speed increases. These differences, about 5 per cent. of the total heat discharged, which will be the subject of further remark, reveal no inconsistency in the observed results, which so far check each other. On the other hand, in the trials 41, 35, 40 (without jackets), while the observed discharges (for trials 35 and 40) are from 1 to 2 per cent. below those calculated, allowing a margin for external radiation, the observed discharge for trial 41 is about 5 per cent. larger than the calculated, an inconsistency which shows error of observation somewhere. Table II does not supply sufficient evidence to locate the error, but this is found in Table I in the quantities given under the head radiation (line 41).

This radiation is obtained as the balance of the total heat received from the boiler (in the water from the hot-well as dry

steam, and in the jacket water), and the total heat discharged as heat and work; hence any error in measuring the heat discharged, or the water from the hot-well, would affect the apparent radiation. Since all the trials without jackets are made under approximately the same radiating conditions, and these conditions are such as would cause slightly less radiation than the trials with jackets, the actual radiation in the trials without jackets must have been nearly the same, and somewhat less than in the trials with jackets. In Table I the radiation for trial 41 is 503 thermal units per minute, 897 for 35, 1,170 for 40, and 1,266 for the trials with jackets, so that the radiation in trial 41 is clearly some 500 thermal units per minute too small. This might be due to an error either in the hot-well discharge or in the heat discharge; but as the former would affect the heat per lb. of coal (line 62), and so bring this trial out of accord with the others, it seems that the error is in the heat discharged.

The correction that would bring the observed heat discharged in Table II, trial 41, into accord with the others is 60 thermal units per lb., or 460 thermal units per minute, which heat, transferred to the radiation, would bring this to 963, or nearly the mean of that for trials 35 and 40. This shows the completeness of the check throughout these results.

The Radiation.—The slight differences which are shown in this quantity, Table I, line 41, for all the trials with jackets, may have been due to differences of temperature in the engine-room. The mean radiation with 200 lbs. steam in the jackets is 1,266 thermal units per minute, and the mean radiation in the trials with the cylinder jackets shut off (omitting 41) is 1,037, the difference being 229, with or without jackets, at a pressure of 200 lbs. per square inch. This is exclusive of radiation from the boiler.

The Heat Abstracted during Exhaust.—That during the exhaust the water in the cylinder, which has resulted from condensation, is re-evaporated by heat from the walls is well established, and it has been often suggested that the steam leaving the cylinder may be somewhat superheated by the hot walls of the passages. The excess of the observed heat discharged over that calculated in Appendix, Table II, might be explained by the second of these causes, but not by the first, since the diagrams all show that the steam was in the condition of dry saturated steam at release; besides which, the calculated heat takes account of all the heat it could so possess. To account for this difference, which amounts to 5 per cent. of the total heat discharged, by supposing the steam superheated would be to suppose the temperature of the steam

raised from 70° to 100° above the temperature of the condenser. Considering that the temperature of the steam in the jackets was 250° higher than that in the condenser, there would be nothing apparently impossible in thus superheating the steam while passing through the ports and exhaust passage heated by the jackets. Such a rise of temperature would, however, be apparent in the exhaust pipe if sought for; and as thermometers showed that the temperature of this did not rise at any time to more than 140° Fahrenheit, which temperature corresponded with the pressure of steam in the condenser, it is evident that this heat did not go to raise the temperature of the effluent steam. The fact that the difference varies so little with the speed of the engine suggests that this absorption of heat is consequent, in some way, on the mechanical action to which the steam is subject during exhaust, in a similar manner to that in which the heat supplied by the jackets to the cylinder is consequent on the expansion, and this appears to be the case.

The steam in the cylinder at release expands down to the pressure of the condenser. The expansion takes place partly in the cylinder, partly in the passages, and will be attended by liquefaction similar to that which results from ordinary expansion. The liquid, thus formed, may be re-evaporated, from the hot walls of the cylinder and the passages, without raising the temperature of the steam above that of the condenser. This expansion is from the volume (per lb.) at release to the volume (per lb.) at the pressure in the condenser, and the amount of heat for re-evaporation can be definitely estimated. In trials 44, 35, 56 respectively, this heat amounts to 84, 87, 71 thermal units per lb. of steam. Some considerable portion of the heat would be supplied from the work done by the steam against the resistance in the passages, which would be directly reconverted into heat; but the greater portion would have to be obtained from the surfaces, or else the steam would enter the exhaust in a supersaturated condition. The excesses of the observed heat over the calculated, Appendix, Table II, are 64, 29, 31 thermal units per lb., being well within the heat necessary to re-evaporate the water, after making allowance for the friction of the passages. This heat, it is to be noticed, is acquired by the steam from the walls after the steam has done its work in the cylinder, and must be supplied either by the jackets or by the condensation in the steam-chest, ports, and cylinder. It therefore represents heat which passes direct through the engine, without effecting any work, and is a loss of between 3 and 6 per cent. of the theoretical efficiency of the steam.

The Diagrams have been taken with six Crosby indicators, and with springs as low as the speeds and pressures would admit.

The reduction is effected by measuring ten breadths, the pressure and back-pressure from the atmospheric line, and then the effective pressure, so that the results check, and may be directly used to obtain a mean diagram. These results have been several times checked by a planimeter, without establishing any sensible difference. As regards the diagrams themselves, every precaution has been taken to ensure accuracy, and there is no reason to suppose that there are any prevailing errors of 1 per cent., although errors of the instruments, and, indeed, of all indicators, when subjected to certain particular tests, are much greater than this. The check afforded by the brake-power, although it would not reveal a prevailing error of 2 or 3 per cent., has this important effect, that it does away with any possible bias that might result from enthusiasm to obtain high indicated power, for by so doing the effect would be to lower the mechanical efficiency of the engine.

It is, however, the consistent agreement of the curves of expansion, as indicated, with the theoretical curve for the weight of absolute steam shown by the water discharged to have passed through the engine, that gives the greatest confidence in the indicated results.

The Reduction of the Diagrams to a mean Compound Diagram.—Considering the important place which must be occupied by mean compound diagrams, in comparing the results of the various trials in such an extended investigation of the steam-engine, it was necessary that some system of reduction should be adhered to, and the choice of this system was a matter of the first importance. There was one peculiarity about the working of these engines which necessitated a departure from any methods previously adopted, namely, the unequal speeds of the three engines. This fact had great influence in determining the system adopted. Except as affected by this, the methods of reduction did not differ from one or other of the plans usually followed.

The reduction of the twenty-four diagrams, taken during a trial from each engine, is effected by finding the means of each of the twenty measured distances from the atmospheric line, which are then reduced to a common scale, 10 lbs. to an inch. These ordinates are then plotted, so as to project the diagram to a length determined, as will be subsequently described. The volumes of clearance, 4 per cent. on engine I, and 6 per cent. on engines II and III, valve-clearance 1·65 per cent. on engine I, and 2·5 on engines II and III are then added to obtain the line of zero volume.

Thus, a compound diagram is obtained showing the relation of volumes and pressures of the whole steam in each of the cylinders. To reduce this diagram, to show the relation of volume and of pressure of the steam discharged from the cylinder, an ideal compression-line is drawn through the point of the actual compression-curve which corresponds to the closing of the exhaust. Horizontal lines are next drawn across the diagram, cutting the expansion-curve, the compression-line, and the ideal line, and each of these horizontal lines is set back until the point which was the ideal compression-curve reaches the line of zero volume. Then the positions taken by the points from the expansion-line and the actual compression-line show the volume of steam in the cylinder over and above the volume of that which is shut in at exhaust. All this reduction may be done arithmetically, or by plotting. The result is that, while the area of the diagram has not been altered, the actual expansion and compression-line for the steam passing through the engine is obtained; Rankine's curve of saturation for the weight of steam discharged is then drawn. On account of the varying difference between the speeds of these engines, the lengths for the compound diagram could not be obtained by simply projecting the lengths of the separate diagrams, so that they should be proportional to the effective volumes of the several cylinders. It was necessary to project them so that they should be proportional to the products of the effective volumes of each engine multiplied by its revolutions per minute. Slight as this necessary modification may appear, it does away with the idea of a relation between the area of a diagram and the size of the engine, which, once got rid of, leaves it apparent that the separate diagrams express nothing but the relation which holds between the pressures and volumes of a certain quantity of steam, which quantity may be changed by altering the scale of length of the diagrams. Having once realized this, the advantage becomes apparent, in instituting comparisons between a number of engine trials, of taking the common scale of length for the diagrams to be such that they all express the relation between the volume and the pressure of the common unit (1 lb.) adopted for the weight of steam. This common scale is readily obtained by dividing the product of effective volumes, multiplied by revolutions, by the weight of steam passing through the engines per minute, and taking the result as the length of the diagram in any uniform scale; ½ inch to the cubic foot has been that adopted for the first reduction in these trials, the pressures being plotted to 10 lbs. to an inch.

The diagrams, Plate 4, Figs. 14, are such mean diagrams, showing

the lbs. per square inch pressure and cubic feet volume for each lb. of steam passing through the engines, also Rankine's curve for saturated steam to the same scale. In these diagrams:—

The extreme length of the diagram	=	the effective volume swept by the piston for each lb. of steam through the engines.
The distance from the line of zero volume to the expansion or compression-curve at any particular pressure . . .	=	the volume of the steam in the cylinder at that pressure, less the steam shut in at compression per lb. of steam through the engine.
The area enclosed in the diagram	=	effective work per lb. of steam.
The distance between the compression-line and that of no volume measures on the right	=	volume of initial steam per lb. of steam rendered non-effective by clearance.
The distance between the expansion-line and the saturation-curve.	=	volume of steam per lb. of steam through the engines absent on account of condensation, priming and leakage.
The ratio of the horizontal distances from the line of zero volume to the curve at cut-off and release	=	the effective ratio of expansion.

The clearness and simplicity of the comparison which these diagrams institute between the areas actually occupied, and those which would have been occupied had the steam been saturated, renders it possible, as well as desirable, to state exactly in what relation the areas stand as regards the theory and economy of the engine.

The area enclosed between the limits of pressure and volume by the line of zero volume, the line of condenser pressure, and the saturated curve, expresses in foot-lbs. the greatest possible amount of heat that can be converted into work, through the agency of 1 lb. of steam maintained in a state of saturation between these limits. The areas included in the measured diagrams represent the heat which has been so converted by the agency of each lb. through the engines, and the various intervening areas represent loss in conversion.

These are facts which it is important to bear in mind in dealing

with jacketed engines, in which 1 lb. of steam through the engines does not represent a certain quantity of heat, which will be the same whether it is realized or not. For such engines it is impossible to make the diagrams represent the comparative efficiencies actual and theoretical. With unjacketed engines, the case is different, as the lb. of steam represents, at a particular pressure, a definite quantity of heat through the engine, however much of it is converted, and if a special adiabatic line be substituted for the saturated line, the relation of areas will be the relation of efficiencies. In the present case, however, it seemed better to treat all the diagrams in the same way, and to make a separate comparison of the efficiencies with the highest theoretical efficiency between the same limits. With the unjacketed as well as with the jacketed trials, the theoretical efficiency has been calculated as for saturated steam. This comparison for all the trials is given in Appendix, Table III.

The Condensation, Priming and Leakage of Steam in the Cylinders, as shown in the Diagrams.

There are two quantities which it is almost impossible to separate by the inherent evidence of the diagrams.

The missing quantity, to use Mr. Willans' expression, which is here shown by the horizontal breadth of the black band, may equally well arise from the steam having escaped by the piston, or having been temporarily converted into water.

This much, however, is evident from the diagrams, that with steam in the jackets, in whatever manner the steam has vanished in the high-pressure engine, it has all re-appeared before the end of the stroke in the intermediate engine, and though some of it has disappeared at the cut-off in the low-pressure cylinder, it has re-appeared again before the end of the stroke. Hence it seems that there is no escape of steam by the pistons of these two engines.

The question remains, however, as to whether steam has not escaped by the pistons of the high-pressure engine, and through the valves, during expansion into the cylinders of the intermediate and low-pressure engines.

Certain differences in the diagrams taken from No. II engine, when working with different cuts-off, suggested that the rider valves were held somewhat off the back of the main valve by the spindle, so that they leaked steam until the pressure in the cylinder was sufficiently lower than that in the steam-chest to spring the spindle and force the valves home. It became particularly

evident in the fifty-fifth trial, and then the cover was removed and the conclusion verified. This source of error was put right, and the fifty-sixth trial, as compared with the earlier ones, shows what has been the effect of leakage in these, namely, the breadth of the black band towards the tops of the diagram from No. II engine.

When the covers were last put on, in August, 1888, the cylinders and valve-faces were all in equally good condition, and there has been no leak from the jackets, while the engines were standing with full pressure in the jackets. The regulators opening into the intermediate receivers were made tight in August, 1888, and were not again opened till after the forty-sixth trial. There was then occasion to open them, and as the engines were standing preparatory to starting the fifty-sixth trial, it was seen that steam was leaking into No. II receiver, probably about ½ lb. per minute; as the valve was found to be shut, there was nothing to be done, so the trial was run; and, as was to be expected, the diagrams from No. I engine show what, considering the circumstances, is an unusually large black band.

In the absence of definite evidence of leakage, the Author concludes that the missing quantity shown by the black band is everywhere due to condensation.

It is not the intention in this Paper to endeavour to establish a complete theory of cylinder-condensation. Though it may be well to state that, before designing the engines, the theory was carefully considered and formulated, leaving only the arbitrary constants to be determined from the experiments. For anything like a complete determination of these constants, the experiments have not sufficiently advanced; but this is not necessary to show that in the case of a series of cylinders, all jacketed up to boiler-pressure, the law of condensation would be precisely that which is shown in the diagrams.

Whenever the bounding surfaces are colder than the steam adjacent to them condensation occurs. To prevent condensation it is therefore necessary to maintain all parts of the cylinder surfaces, and port passage surfaces, at a temperature at least as high as that of the initial steam.

To do this, in the case of expansion, it is not sufficient (as seems to be commonly assumed) to keep the outside of the metal constituting the walls and covers, merely at the temperature of the initial steam. That, of course, would be sufficient if there were no condensation other than what results from the temperature of the surfaces.

Forty years ago no such other cause of condensation was known.

It was revealed, however, by the discoverers, Rankine and Clausius, in 1849, that the expansion of steam reduces its temperature below that corresponding to saturation unless some of the steam is condensed. The manner of action of this supersaturation, caused by expansion in absorbing heat from the walls of the cylinder maintained at a higher temperature than the steam, does not appear to have been yet ascertained with any degree of certainty; but it is certain that steam in this state of supersaturation does absorb heat with immense rapidity, when the walls are at a higher temperature than the expanded steam. Also the amount of heat necessary to prevent supersaturation is definitely known, though it is, perhaps, well to recall the fact that it is not, even approximately, the heat equivalent of the work done by the steam during expansion.

If the walls of the cylinders are maintained at the temperature of the initial steam, the expanding steam will absorb heat. This heat must pass through the walls; and as heat only flows through metal down the gradient of temperature, the temperature on the outside must be greater than that on the inside. Hence it follows that either the steam in the jackets must be hotter than the initial temperature of the steam in the cylinder, or the mean temperature of the internal surface of the cylinder will be below that of the initial steam, in which case there will be cylinder-condensation.

How important this degradation of temperature through the walls is, wlil, perhaps, best be rendered apparent by stating an actual case.

In expanding 1 lb. of steam from a pressure of 203 lbs. to a pressure of 79·3 lbs., the heat per lb. necessary to prevent supersaturation is

55·1 T. U.

or about 5 per cent. of the total heat in the initial steaming. In a cylinder passing 600 lbs. of steam per hour, to prevent supersaturation there should pass through the walls of the cylinder

33,060 T. U.

Now the jacketed surface of the cylinder of the HP. engine is less than 1·5 square foot, and the thickness of the metal is more than 0·4 inch. Hence the heat would have to flow through this thickness of metal at a rate of

22,000 T. U. per square foot per hour.

From the known laws of conductivity of iron, this would require a difference of temperature of 38° Fahrenheit.

Thus it appears that, to prevent supersaturation, the temperature of the steam in the jackets of No. I engine must be 38° higher than the mean temperature of the internal steam; or, in other words, that the mean temperature of the internal surfaces will be 38° lower than that of the initial steam, which is at the same temperature as that in the jackets.

What amount of surface-condensation this difference of temperature would cause may be, to some extent, inferred by comparison with the difference between the mean temperature of the surfaces and that of the initial steam when the jackets are empty. Here the initial temperature is about 383°, and that of the exhaust, 302°; the mean, 342°; difference of mean and initial, 41°; so that in this engine the mean temperature of the walls would only be affected to the extent of about 3° Fahrenheit by the jackets, supposing the whole of the heat to prevent supersaturation were supplied by the jackets. But this would not be quite the case, as some heat is obtained from the difference in the heat given up and absorbed by the cylinder-condensation; and there is no proof that the steam may not be discharged with a certain degree of supersaturation.

However, the reasoning leads to the conclusion that, with steam at initial pressure in them, the jackets would produce a comparatively small difference on the cylinder-condensation in this engine when passing 10 lbs. of steam per minute.

In No. II, the intermediate engine, the case is different. Here the heat which has to flow into the cylinder through the walls is nearly the same as in No. I; but the surfaces are double as large and of the same thickness, so that the fall of temperature would be about one-half, or 20°. The temperature of the steam in the jackets is 81° above that of the initial steam, and the internal walls would still be 60° above the initial temperature. Hence there should be no condensation on those surfaces which are jacketed. Still there are in this engine, although much less than is usual in jacketed engines, portions of the surfaces which are not, so to speak, jacketed, mainly the surface of the ports and of the piston; and though these derive heat from the jackets, it is through a much greater thickness of metal, and hence would require a much greater difference of temperature to prevent condensation. Thus, even with the jackets at a temperature of 60° above that of the steam, there should probably be some initial condensation.

In No. III engine the jackets have a temperature of 140° above

the steam, hence the initial condensation should probably be much less than in No. II.

The diagrams (Plate 4, Figs. 14) show that this is the case. They exhibit a little condensation, which seems to increase from cut-off until the expansion reaches about 1·5 or 2, and it then diminishes to zero. The increase after cut-off may be owing to the inertia of the indicator piston depressing the curve, as the springs used have always been as weak as possible on account of the low pressure.

They also demonstrate conclusively, with such jacketing as there is in these cylinders, that a temperature of 140° in the jackets above the initial temperature is sufficient to prevent sensible cylinder-condensation with as much as 720 lbs. of water per hour passing through the cylinders.

The diagrams for the trials 41, 35, 40, show the condensation when the jackets are empty. These three diagrams are from trials as nearly as practicable corresponding in power with those with the jackets on. They are reduced to show the volume per lb. of water through each engine, and the outside curve is the saturation-curve for 1 lb. of steam; the horizontal breadth of the black band, therefore, represents volume of steam missing. This includes the volume missing on account of the condensation resulting from expansion in each cylinder as well as on account of cylinder-condensation. It is to be noticed, however, that the steam probably entered each steam-chest dry, so that the only water in excess of cylinder-condensation is that resulting from expansion in that cylinder. This would be represented by a curve drawn from the points in the saturation-curve corresponding in pressure to the points of cut-off, and gradually diverging inwards from the saturation-curve, until at release the horizontal divergence should be about 5 per cent. of the horizontal breadth of the white diagram at that pressure.

The great excess of condensation in the intermediate cylinder over the high-pressure, and in the low-pressure cylinder over the intermediate, is very apparent. This fully explains the difference in the relative speeds of the engines with and without the jackets already mentioned, the speed of No. III compared with No. I being as 1·5 with jackets to 1 without jackets.

The distributions of condensation are very similar in the three cylinders. The ratios which the steam condensed bears to the steam passing through the engines at cut-off, middle stroke, and release, are shown in Appendix, Table IV.

The testing of the boiler was carried only so far as was necessary

to check the results of the trials. No chemical tests were taken of the air or coal.

The coal used was Nixon's Navigation mixture, weighed as it came from the heap in the boiler-house. In most of the trials the feed was carefully measured, with the result, already mentioned, that it was from 5 to 10 per cent. greater than the discharge from the hot-well.

Taking the feed, these trials show that the boiler generally evaporated 10·4 lbs. of water per lb. of coal with the pressure 195 lbs. and the feed at 130°. This, if all the water were evaporated, would give 11,350 units of heat per lb. of coal.

The temperature at which the gases left the boiler was 500°, and after passing the water heater 250°, the rise of temperature in the water-heater being about 100°.

The source of the loss of water was not discoverable, so that it was not possible to determine whether it escaped as water or steam; and until this point could be determined it was impossible to say from observations on the boiler what the quantity of heat obtained in the boiler might be. The results in Table I are therefore confined to the steam received by the engines.

The Paper is accompanied by several drawings, diagrams, and a photograph, from which Plate 4 and the *Fig.* in the text have been engraved.

TABLE I. MEAN RESULTS of TRIPLE-

	State of the steam-jackets . . . . {
1	Number of the trial . . . .
2	Date of the trial . . . .
3	Time of trial . . . . {
4	Lbs. on the square inch mean absolute pressure in the boiler . . .
5	" " " " " receiver No. I . .
6	" " " " " " No. II .
7	" " " " " " No. III .
8	" " " " " condenser . . .
9	Lbs. on the sq. inch mean effective pressure indicated in engine No. I .
10	" " " " " " " No. II
11	" " " " " " " No. III
12	Revolutions per minute of engine No. I . . . .
13	" " " No. II . . . .
14	" " " No. III . . . .
15	I.HP. engine No. I . . . .
16	" " No. II . . . .
17	" " No. III . . . .
18	Lbs. × feet load on brake No. I . . . .
19	" " " " No. II . . . .
20	" " " " No. III . . . .
21	Brake HP. engine No. I with intermediate shaft . . . .
22	" " No. II " " . . . .
23	" " No. III " " . . . .
24	Mechanical efficiency of engine No. I with intermediate shaft . . .
25	" " " No. II " " . . .
26	" " " No. III " " . . .
27	Total I.HP. . . . .
28	Total B.HP. . . . .
29	Mechanical efficiency of engines I, II, III with intermediate shafts . .

EXPANSION TRIALS on SEPARATE BRAKES.

Cylinder jackets at boiler-pressure. Receiver jackets „ „			Cylinder jackets empty. Receiver jackets at boiler-pressure.		
44 Feb. 12, '89 9·52 to 3·51 P.M.	33 Dec. 4, '88 9·45 to 4 P.M.	56 April 2, '89 9·57 to 2 P.M.	41 Jan. 29, '89 9·54 to 3·55 P.M.	35 Dec. 11, '88 9·54 to 4·6 P.M.	40 Jan. 22, '89 10·32 to 2·37 P.M.
200·0 199·0 65·0 21·8 1·5	201·0 198·0 74·0 22·7 1·7	207·0 203·0 85·0 22·6 2·2	205·0 204·0 67·0 21·7 1·3	206·0 205·0 73·0 23·1 1·8	203·0 201·0 78·0 25·6 2·5
73·7 29·12 12·02	70·53 28·99 11·71	71·1 33·27 12·52	72·61 30·66 12·15	73·8 28·2 11·19	75·56 29·81 11·61
115·0 135·0 152·0	206·0 241·0 249·0	230·5 298·0 299·0	146·0 127·0 109·0	229·0 215·0 184·0	322·0 320·0 276·0
8·06 9·85 15·32	13·82 17·54 24·4	15·6 24·8 31·7	10·07 9·73 11·12	16·11 15·17 17·23	23·11 23·86 26·90
300·0 320·0 400·0	300·0 320·0 400·0	300·0 320·0 420·0	300·0 320·0 400·0	300·0 320·0 400·0	300·0 320·0 400·0
6·56 8·21 11·55	11·74 14·65 18·93	13·13 18·12 23·9	8·32 7·72 8·29	13·05 13·07 13·98	18·35 19·46 21·00
0·812 0·835 0·753	0·848 0·835 0·775	0·844 0·73 0·754	0·825 0·793 0·75	0·810 0·861 0·81	0·794 0·815 0·780
33·23 26·32	55·76 45·32	72·1 55·15	30·92 24·33	48·51 40·1	73·87 58·81
0·792	0·813	0·765	0·79	0·826	0·80

TABLE I.-

	State of the steam-jackets
	Number of the trial
	Date of the trial
	Time of trial
30	Lbs. per minute of water passing through the condenser
31	Degrees Fahrenheit initial temperature " "
32	" " final temperature " "
33	T.U. per minute taken up by " " "
34	T.U. discharged as I.HP. per minute
35	T.U. per minute discharged as I.HP. and in condensing water
36	Thermal efficiency as given by heat discharged in condensing water
37	Lbs. water discharged from hot-well per minute
38	Degrees Fahrenheit temperature in the hot-well
39	" " " " " above temperature of feed
40	T.U. per minute discharged from the hot-well
41	" " " by radiation
42	" total per minute discharged from engines
43	T.U. necessary to evaporate 1 lb. of feed to economizer
44	" per minute received as dry steam (= lbs. discharged from hot-well)
45	" received from each lb. of water condensed at boiler-pressure
46	Lbs. per minute of water from the jackets, &c.
47	T.U. per minute received from the water from the jackets, &c.
48	Total T.U. received per minute by the engines
49	Degrees Fahrenheit temperature of feed to the economizer
50	Degrees added to temperature of feed in economizer
51	Lbs. per hour of water discharged from the hot-well
52	T.U. " received by water " " " in the economizer
53	Lbs. jacket-water per hour returned to the feed-pipe into the boiler
54	Degrees Fahrenheit temperature of the boiler
55	Degrees mean temperature observed after mixture with feed
56	Lbs. per hour of mixed feed to boiler
57	T.U. to evaporate 1 lb. of mixed feed
58	" per hour taken up in the boiler
59	T.U. per hour received from the furnace (exclusive of steam lost)

continued.

Cylinder jackets at boiler-pressure. Receiver „ „ „			Cylinder jackets empty. Receiver „ at boiler-pressure.		
44 Feb. 12, '89 9·52 to 3·51 P.M.	33 Dec. 4, '88 9·45 to 4 P.M.	56 April 2, '89 9·57 to 2 P.M.	41 Jan. 29, '89 9·54 to 3·55 P.M.	35 Dec. 11, '88 9·54 o 4·6 P.M.	40 Jan. 22, '89 10·32 to 2·37 P.M.
209·5	434·0	453·1	264·0	337·5	403·0
49·9	68·0	55·45	51·83	64·0	52·26
79·83	91·03	83·87	83·03	98·03	94·94
6,271·0	9,994·0	12,862·0	8,236·0	11,484·0	17,200·0
1,421·0	2,384·0	3,085·0	1,325·0	2,074·0	3,158·2
7,692·0	12,378·0	15,947·0	9,561·0	13,558·0	20,358·0
0·185	0·192	0·194	0·141	0·153	0·155
5·83	9·58	12·34	7·73	11·47	17·58
102·0	114·0	112·7	108·0	114·0	132·5
22·0	0·0	28·9	25·0	0·0	0·0
128·0	0·0	356·0	200·0	0·0	0·0
1,227·0	1,394·0	1,176·0	503·0	897·0	1,170·0
9,047·0	13,772·0	17,479·0	10,264·0	14,455·0	21,528·0
1,151·0	1,117·0	1,147·0	1,148·0	1,117·0	1,098·0
6,710·0	10,700·0	14,154·0	8,874·0	12,812·0	19,303·0
844·0	844·0	842·0	843·0	843·0	843·0
2·77	3·64	3·95	1·65	1·95	2·64
2,337·0	3,072·0	3,325·0	1,390·0	1,643·0	2,225·0
9,047·0	13,772·0	17,479·0	10,264·0	14,455·0	21,528·0
80·0	114·0	83·8	83·08	114·0	132·5
95·5	83·8	130·7	98·5	76·1	107·7
349·8	574·8	740·4	463·8	688·2	1,054·8
33,500·0	48,200·0	96,800·0	45,700·0	52,500·0	113,600·0
166·2	218·4	237·0	99·0	117·0	158·4
383·0	383·0	383·0	383·0	383·0	383·0
244·0	250·0	257·0	218·0	219·0	260·0
516·2	793·2	977·4	562·8	805·2	1,213·2
987·0	981·0	974·0	1,013·0	1,012·0	971·0
509,300·0	778,100·0	951,900·0	570,100·0	814,800·0	1,178,000·0
542,800·0	826,300·0	1,048,700·0	615,800·0	867,300·0	1,291,600·0

TABLE I.—

	State of the steam jackets	
	Number of the trial	
	Date of the trial	
	Time of trial	
60	T.U. per lb. of coal taken up in the economizer	
61	„ „ „ „ boiler	
62	„ „ „ total	
63	T.U. per I.HP. per hour for radiation	
64	„ „ „ for the engines	
65	„ „ „ total	
66	Lbs. per I.HP. per hour of feed-water to supply as dry steam the heat for	radiation
67		the engine
70		total
71	Lbs. of coal per hour (Nixon's Navigation mixture) for	radiation
72		working the engines
73		total
74	Lbs. of coal per I.HP. per hour for radiation	
75	„ „ „ „ working the engines	
76	„ „ „ „ total	

TABLE II.

——		Jackets at Boiler-Pressure.			Jackets Empty.		
Number of the trial		44	33	56	41	35	40
Thermal unit from the condenser per lb. of water from the hot-well	Calculated	1,011	1,014	1,011	1,014	1,009	990
	Measured	1,075	1,043	1,042	1,065	1,001	978
	Differences	−64	−29	−31	−51	8	12

continued.

Cylinder jackets at boiler-pressure. Receiver jackets „ „			Cylinder jackets empty. Receiver jackets at boiler-pressure.		
44	33	56	41	35	40
Feb. 12, '89	Dec. 4, '88	April 2, '89	Jan. 29, '89	Dec. 11, '88	Jan. 22, '89
9·52 to 3·51 P.M.	9·45 to 4 P.M.	9·57 to 2 P.M.	9·54 to 3·55 P.M.	9·54 to 4·6 P.M.	10·32 to 2·37 P.M.
670·0	646·0	1,006·0	898·0	651·0	950·0
10,186·0	10,436·0	9,895·0	9,961·0	10,103·0	9,850·0
10,856·0	11,082·0	10,901·0	10,759·0	10,754·0	10,800·0
2,216·0	1,500·0	978·0	976·0	1,110·0	950·0
14,120·0	13,320·0	13,567·0	18,969·0	16,768·0	16,535·0
16,336·0	14,820·0	14,545·0	19,945·0	17,878·0	17,485·0
2·0	1·34	0·84	0·84	1·0	0·86
12·2	11·92	11·83	16·45	15·0	15·04
14·2	13·26	12·68	17·3	16·0	15·9
7·0	7·5	6·4	2·8	5·0	6·4
43·0	67·06	89·8	54·44	75·65	113·2
50·0	74·56	96·2	57·24	80·65	119·6
0·21	0·13	0·09	0·09	0·10	0·09
1·29	1·24	1·24	1·76	1·56	1·53
1·50	1·33	1·33	1·85	1·66	1·62

TABLE III.—RELATIVE AREAS of DIAGRAMS per LB. of STEAM THROUGH the ENGINES, and THERMAL EFFICIENCIES of ENGINES.

	Number of trial	44	33	56	41	35	40
1	Theoretical area, ft. & lb.	238,645	233,545	228,420	235,500	233,000	221,860
2	Measured area „	188,096	192,067	192,000	127,545	139,546	144,350
3	Percentage of theoretical area	79·0	82·0	84·0	54·0	60·0	65·0
4							
5							
6							
7							
8	Theoretical efficiency, p.c.	23·3	23·2	22·7	23·3	23·2	22·4
9	Measured efficiency, p.c.	18·5	19·2	19·4	13·8	15·3	15·5
10	Percentage of theoretical efficiency	79·4	82·6	85·4	59·2	65·9	69·4

TABLE IV.—CONDENSATION WITHOUT JACKETS.

—	Number of the Trial.	Revolutions per Minute.	Ratio of Expansion.	Proportion of Total Steam condensed at		
				Cut-off.	Mid-Stroke.	Release.
Engine No. I	41	146	2·7	0·40	0·39	0·30
	35	229	2·3	0·29	0·27	0·22
	40	322	2·0	0·22	0·21	0·17
Engine No. II	41	127	2·4	0·41	0·345	0·29
	35	215	2·4	0·38	0·34	0·26
	40	320	2·2	0·30	0·27	0·14
Engine No. III	41	109	2·7	0·51	0·48	0·37
	35	184	3·05	0·48	0·47	0·33
	40	276	2·6	0·32	0·36	0·23

ABSTRACT.

The following summary of the foregoing Paper as supplied by the Author, having been referred to in the course of the discussion, is here reprinted :—

The modern theory of the steam-engine, as founded on the discoveries of Joule, had rendered the experimental investigation of it one of the most important and most interesting branches of science. This theory revealed in the most certain manner the objects to be aimed at in designing engines, as well as the results to be expected; but only experimental investigation of the engines showed how far these results had been realized, and to what circumstances any failure in such realization must be attributed. For this purpose, ordinary steam-engines, doing ordinary work, were about as good as ordinary animals, in their ordinary occupation, were for subjects of physiological experiment. In certain particulars both could be accurately observed, as, for instance, how much coal or food was necessary during the performance of a particular operation; but to ascertain how all the separate organs were performing their several functions was impossible with an ordinary steam-engine, without subjecting it to a species of mutilation which left it about as fit to continue ordinary work as an animal that had been the subject of physiological study. By the patient expenditure of great ingenuity in adapting measuring instruments to the engines, as well as by securing provisions, during the construction of the engines, for the use of these instruments, much had been done. Engines of every class had from time to time been subjected to experimental examination as complete as practicable, and the knowledge thus gained was of immense value, although it left much to be desired. It had been found by these experiments that the actions in the several organs did not even approximately conform to the simple primary actions aimed at; but that the primary were obstructed by secondary actions, which in some cases amounted to as much as 40 or 50 per cent. of the total action. The analysis and evaluation of the secondary actions thus revealed, although recognized as objects of primary consideration in engine-trials, were still very incomplete, demanding for attainment engines much more fully adapted to the purpose of experiment than those hitherto available. It was evident that the engines and apparatus for operating upon should be such, that each organ, while similar to, and performing the part of, the corresponding organ in an ordinary engine, should be so arranged with respect to the other organs, as to admit of the manner in which it performed its part being completely gauged; and that this should be simultaneously with all the organs, both those corresponding to the ordinary engine and such special organs as should be introduced to admit of access to the others, so that the action of these latter might be accurately discounted. The engines in the Whitworth Engineering Laboratory had been throughout specially designed and constructed with a view to the fulfilment of the foregoing requirements. The Committee, consisting of Mr. John Ramsbottom, Mr. John Robinson, and the Author, having, after consultation with Mr. William Mather, been released from all considerations of expense, felt that a great opportunity would be lost if the facilities offered were not taken advantage of to the utmost; and unless every effort was made so that the engines, while as far as possible representing in their principal members the most approved existing practice in steam-engine con-

struction, should be thoroughly available for experiments on the use of steam throughout, and, if possible, beyond, the range hitherto attained in practice. If this was accomplished, not only would appliances, costly almost beyond the range of private effort, be secured, but the conduct of what would otherwise be a very expensive and laborious research would afford the most desirable work for the laboratory—work which, having all the advantages of reality, would yet afford the Students the best possible opportunity, while acquiring facility in the use of the instruments and methods of reduction, of gaining an insight into the action of each part of the engine. There were three separate inverted-cylinder engines working on separate brakes, having the following dimensions:—

Engine.	Cylinder.		Crank-Shaft Diameter.
	Diameter.	Stroke.	
	Inches.	Inches.	Inches.
No. I (high-pressure) . .	5	10	$2\frac{3}{4}$
„ II (intermediate) . .	8	10	$2\frac{3}{4}$
„ III (low-pressure) . .	12	15	4
Air-pump on No. III . .	9	$4\frac{1}{2}$	
Feed-pump „ . .	$1\frac{1}{2}$	2	

All the engines had their cylinder walls and both covers separately jacketed, and so arranged that they could be worked with or without steam in any or in all of the jackets. Each engine was designed to carry a pressure up to 200 lbs. on the square inch, to run at any piston-speed up to 1,000 feet per minute, and had expansion-gear to cut off from zero up to 0·8 of the full stroke. One engine was furnished with a surface-condenser having 160 square feet of surface; the other two engines were furnished with alternative exhausts, either into the atmosphere or into steam-jacketed receivers supplying the next engine, each receiver having an alternative supply of steam from the boiler. The boiler was of the locomotive type, with 5 square feet of grate, 200 square feet of heating-surface, and carried 200 lbs. of steam per square inch. It was set in a hot chamber, with an economiser having 50 square feet of heating-surface, of which an area of 40 square feet was kept clean by scrapers, and was so arranged that the gases moved in the opposite direction to the water. The furnace was worked either with chimney-draught or with forced draught on the closed stoke-hold system, and burnt fuel up to 160 lbs. an hour. The speciality of the system consisted, mainly, in the provisions made to render possible the accurate determination of the manner in which each part performed its work, as well as to make the performances of each organ, as far as practicable, independent of the performance of the rest. To accomplish this, the boiler and three engines had been separated by intervals of 20 feet, 7 feet, and 12 feet, and the steam distributed by five systems of pipes, while the engine-shafting extended over a length of 36 feet. This spreading out of the engines entailed greatly increased radiation and additional friction. These quantities, however, being differently measurable did not confuse the results. The investigation, commenced in March, 1888, had been continued at the rate of two trials a week during the Session, a trial occupying six, four, or two hours, and being conducted as regular work in the laboratory. As the trials were intended eventually to cover all possible systems of using steam, each system was fully investigated in a series of trials, giving consistent results, before proceeding to another system. After

the first twenty-four trials, a scheme was drawn up, commencing with a series of trials of triple expansion at 200 lbs. boiler-pressure per square inch, with and without steam in the jackets. This series, involving thirty-two trials, was commenced in October, 1888, and completed in April, 1889. Several trials were made at each speed, and the results were found to agree within 1 per cent., so that three trials with steam in the jackets and three without were taken as illustrating the results obtained. The conditions under which this series of trials had been made were, if anything, more favourable to economy than any which prevailed in practice; and although the purpose of these engines was to elucidate the causes of inefficiency rather than to realize the utmost economy, yet it was very desirable that the results obtained should not, whether on account of the comparatively small sizes of the engines, or from other causes, fall greatly behind what might be expected from high-class engines in actual practice. Hence it was eminently satisfactory to find that, notwithstanding the drawbacks already mentioned, the economic results compared favourably with anything yet obtained in practice, even with the largest engines. The lbs. of coal and of water per indicated HP. per hour were:—

	With Steam-Jackets.	Without Steam-Jackets.
Coal—Total	1·50 to 1·33	1·81 to 1·62
Discounting radiation	1·30 „ 1·21	1·77 „ 1·54
Water—Total	14·10 „ 12·68	17·30 „ 15·90
Discounting radiation	12·30 „ 11·90	16·60 „ 15·10

Although these results were extremely good, the sources and extents of the various losses were clearly shown. Thus, of the total heat received by the engines exclusive of radiation, with jackets 19·4 per cent. had been converted into work, and without jackets 15·5 per cent.—the greatest amount which would have been converted had there been no secondary actions being 23 per cent.; so that with steam-jackets there were losses through secondary actions amounting to 17 per cent., and without jackets to 34 per cent. The manner of the distribution of these losses was also apparent. One important source of loss, which with jackets accounted for 5 per cent. of the loss, had been brought to light for the first time. This was the heat carried away from the surfaces of the cylinder and passages, in consequence of the expansion after release. The effects of cylinder-condensation were clearly shown in the mean diagrams taken from the trials. Although these trials were not in themselves sufficient to determine anything like a complete law of this action, they exhibited in a striking manner its dependence on certain circumstances. One circumstance in particular, which had not previously received much attention, was here shown to be of primary importance in the action of steam-jackets. These diagrams showed that with the temperature of steam in the jackets of No. I engine the same as that of the initial steam, the effect of the jackets on the cylinder-condensation was very small. In No. II engine, with 80° Fahrenheit difference in the temperature of the jackets and that of the initial steam, the condensation was reduced from 30 per cent. to 5 per cent.; and a difference of temperature of 180° Fahrenheit between the jackets and the initial steam in engine No. III entirely prevented condensation. Thus, in these trials, with steam at boiler-pressure in the jackets, low-pressure diagrams had been obtained, apparently for the first time, in which the curve of expansion coincided exactly with the curve for saturated steam.

[DISCUSSION.

Discussion.

Sir John Coode. Sir JOHN COODE, President, said the Author had presented the description of, and the results obtained by, these remarkable engines in every possible point of view, and whether in regard to the conditions laid down by the Committee of consultation, or to the admirable manner in which those conditions had been carried out by Messrs. Mather and Platt, the results were highly creditable to all concerned. The Author stated that the makers had spared neither trouble nor expense in carrying out the work, and those members who had been fortunate enough to see the engine, as he had, would certainly agree with him in that statement. With regard to the expense, the sum paid to the makers represented only one-fourth of the actual cost, the other three-fourths being regarded as a present to the University College. That fact redounded so very much to the credit of Messrs. Mather and Platt that it ought to be widely known.

Professor Reynolds. Professor OSBORNE REYNOLDS said he only wished to direct attention to one fact which he thought had not been sufficiently put forward. In discussing the Paper, it should be borne in mind that the object in making the engine in that form was to render every part of it accessible to observation. That was the main object; it was not to get an economical engine, though it was fairly economical; the object was really to measure everything that could be measured. Every one who saw them must acknowledge that they were very handsome, but still they were a strange looking set of engines. They answered the purpose, however, and the design was simply for the sake of being able to get at all the parts of the engine in order to be able to measure everything about them. There were many complications, particularly in the jackets and in the shafts. The low mechanical efficiency of the engine, which was fairly low, as shown in Table I, was partly due to the great expansion in these totals, and also to the fact that for the sake of getting a good figure in the diagrams the passages had been made abnormally large, the area of the ports being 13 per cent. of the area of the piston. There was also a length of 35 feet of crank-shafting, which diminished the mechanical efficiency of the engine to some extent.

Mr. Cowper. Mr. E. A. COWPER felt that the Author should be thanked for trying to arrange the excellent engine that he had described, so as to get an accurate result of the performance of the steam;

Mr. Cowper.

the object being not to make the most economical engine, but to endeavour by experiments to find how the steam operated in every possible way. It would have been highly interesting to have seen the original indicator diagrams drawn by the engines themselves, as also the friction diagrams. Had he been trying the experiments himself, he should have preferred to make the engines run at one speed, and then the indicator diagrams would have been comparable without any alterations. The diagrams shown, he understood, were average diagrams from a large number of experiments, but altered in proportion to the speeds. Of course, in making such experiments the engine must be in good order; he did not say perfect order, because that was not to be attained, but it must be really good. Unfortunately, up to experiment No. 55, it seemed that the expansion-valve was off the face, viz., that the slide-rod sprung it off the face, and it was not until the steam-pressure was sufficiently low in the cylinder that the valve came up to the face. It was stated in the Paper that there were leaks of steam into the receivers; he should therefore have preferred putting aside those fifty-five experiments and to have gone on to the fifty-sixth, and to have taken a number of others afterwards when the engine was in good order. There seemed to have been an escape varying from 5 to 10 per cent. of feed-water, which should have been stopped before calculating the exact quantity of water that went into the engine. The reverse had been done by the Author, who had taken into account the water coming from the engine, and the calculation of fuel, he understood, was upon that. The fuel for all the steam evaporated from the boiler had to be paid for, and, therefore, engineers were in the habit of estimating the feed-water; but as neither the weight of fuel burnt, nor the quantity of feed-water used, was given in this case, it was impossible to follow out the calculation. He must take exception to the statement that the steam was put into the cylinder as dry as possible, because part of the steam supplied to the engine went first through the jackets. Now the jackets acted to a certain extent in condensing steam, and thereby did very useful duty, keeping the cylinders warm. The steam coming into the engine passed from the boiler dry, but what passed through the jackets became damped. The Author stated that the jackets were made so that the water should drain back to the boilers. The engines were arranged in such manner that the water-line of the boiler was considerably below the water in the separator, the object being that any water that went into the separator should be allowed to return to the boilers by gravity,

Mr. Cowper. and there was a head of 6 feet to effect this. But, as Mr. Cowper had pointed out on former occasions, if the jackets were connected with the boilers to take steam from the boiler, and the bottom of the jackets also connected to the boiler again and the water was allowed to run back, all the air that came over with the steam was lodged in the jackets. In this case the damp steam from the jackets would probably bring most of the air out with it; but the fact that "the jackets were liable to fall off in efficiency" rather pointed to their not having pure high-pressure steam in them. This was not a fanciful objection, but was one practically of great importance, and he always made a point of letting out the air occasionally, or else continuously, from the jackets, so that no air should be lodged in them. Air, of course, would render them inoperative to a certain extent. He approved of the steam-jacketed receivers between each pair of cylinders, having found out the advantage of that arrangement in 1856, when he first introduced them. Cutting off the steam before the half-stroke in each cylinder prevented any second gush of steam into the cylinder whilst the piston was making its stroke, and before the cut-off, and was also very good. The engine, however, not being coupled, interfered somewhat with this, inasmuch as with that arrangement the gush of steam might come from the engine at different times, or just before the moment of cutting off steam. The indicator diagrams of course must vary a little, because of the varying time of one cylinder taking steam from the other; not to a great extent in this case since the steam-jacketed receivers were so very large, but it should be avoided, because the steam should not enter without doing its full duty. He could not but think that there must be some considerable friction in the engine, or else the duty would be greater with 185 lbs. steam and triple expansion. Higher duty had been attained with 55 lbs. steam in a compound engine with only two cylinders, but of large size. He thought, on the whole, the attempt to obtain exact experiments as to the action of steam was praiseworthy, and he should be glad to hear, that in future experiments with those steam-engines, some of the little points had been set right, so that more precise results might be obtained. He did not like to have a suspicion of a valve being on or off the face for part of the stroke.

Professor Unwin. Professor W. C. Unwin agreed with the Author that in building a college engine, a totally different object to that of building a commercial engine had to be kept in view. The most foolish criticism that could be made on a college engine was, that it was not a good type of commercial engine. Not many of the former

Professor Unwin.

engines had been built: but the Author had two advantages; he had come last in building an engine, and he had larger means than others, either directly, or through the liberality of the makers of the engine; and, as he had bestowed much attention and care in the design of the engine, it was not surprising that he had built an extremely good one. It was perhaps fair to recall the fact that the very first college engine built was one arranged by Professor Dwelshauvers Dery, of Liége. That first engine was in many respects the best experimental engine hitherto constructed. It was a simple engine with very remarkable valve-gear especially designed for experimental purposes. There were four valves with port areas one-twelfth the area of the piston. Then in Professor Dwelshauvers Dery's engine the valve-gear was so arranged that not only could the cut-off be varied through the whole length of the stroke, but the lead could be varied to a very considerable amount, and also the compression through the whole range of the stroke. The valve-gear of Professor Dwelshauvers Dery's engine was quite a typical valve-gear for an experimental engine. That engine had separate jackets both to the body of the cylinder and the covers. It had one other remarkable feature. The Author had tried to get the clearance spaces of his engine small, and very rightly so; but apparently not with much success. In his own engine at the Central Institution the clearance in the low-pressure cylinder was less and in the high-pressure cylinder slightly more without any special proportions. Before this engine was built, he designed an engine with Corliss valves, which would have given a much smaller clearance, and it was only want of funds which prevented his adopting Corliss valves; but in Professor Dwelshauvers Dery's engine the minimum clearance was only one-thirtieth of the cylinder volume. He had, three or four years ago, arranged the design of the engine built for the Central Institution.[1] It was a compound engine, differing in some respects from

[1] The experimental engine at the Central Institution had two cylinders 8¼ and 13 inches in diameter and 22 inches stroke, normal speed 100 revolutions per minute; the cylinders were jacketed on the body and back covers. Both cylinders had slide-valves and expansion-valves, and both engines had governors. The engine could be used simple or compound, with or without a condenser, and all the passages not in use at any given time could be blank flanged, so that there should be no leakage. The low-pressure expansion-valve was a Meyer valve. The high-pressure, a Hartnell valve, worked from the governor. But the governor could be put out of gear and the engine worked without it. Practically with a fixed load the diagrams were so similar, even when the engine was under control of the governor, that no object was gained

Professor Unwin.

the Author's engine, and it would be perhaps interesting for a moment to look at the differences. The Owens College engine was a vertical one, but the Central Institution engine was horizontal. A good deal had been made of the point of accessibility, it being said that a vertical engine was the most accessible. He could not understand how an engine in which there were three staircases was more accessible than an engine every part of which could be reached from the floor. The only thing necessary to make a horizontal engine accessible was to separate the cylinders, so that there should be a passage between them. He did not think there was much in that, but still the advantage of accessibility seemed to be on the side of the horizontal engine. In the next place, the most marked difference between the Author's engine and his own was the adoption of the extremely nice expedient of separating the three engines and letting them all go as they pleased. Mr. Thornycroft, when examining his engine three or four years ago, said: "Why did not you make your engines work separately?" He wished that that suggestion had been made twelve months earlier. The Author had the advantage of adopting that suggestion. If he were building a new engine, he should probably adopt the same expedient, but still too much might be made of it. First, it placed the action of the engine on a different plane to that of any engine which could be used for ordinary purposes.[1] It was not a very great objection, but still it had to be recognized. He did not see that it afforded much greater advantage than could be acquired by having a cut-off valve to both cylinders; or that much could be gained by building the engines separately, over what could be obtained perfectly well by varying the cut-off in the

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by putting it out of gear. When working compound, the engine was ordinarily used as a receiver-engine, but the crank angles could be varied. There was a surface-condenser of the Perkins type, and circulating water and condensed steam were separately measured. The clearance could be altered on each cylinder. The jackets drained to a separate measuring tank, and there was no steam-trap. There was a band friction-brake on a wheel, cooled inside by water on Mr. Halpin's plan. The engine was built for a steam-pressure of 150 lbs. per square inch, but had only been used at present with 70 lbs. pressure. The engine was designed in detail and very carefully constructed by Messrs. Marshall and Sons, of Gainsborough. The longest stroke and most moderate number of revolutions had been deliberately adopted, as best suited for students' purposes.

[1] The cylinder condensation being proportional (other things being equal) to the duration of a stroke, the action of the cylinder sides would be comparable with that in ordinary engines, only when all the cylinders had the same number of strokes per minute.

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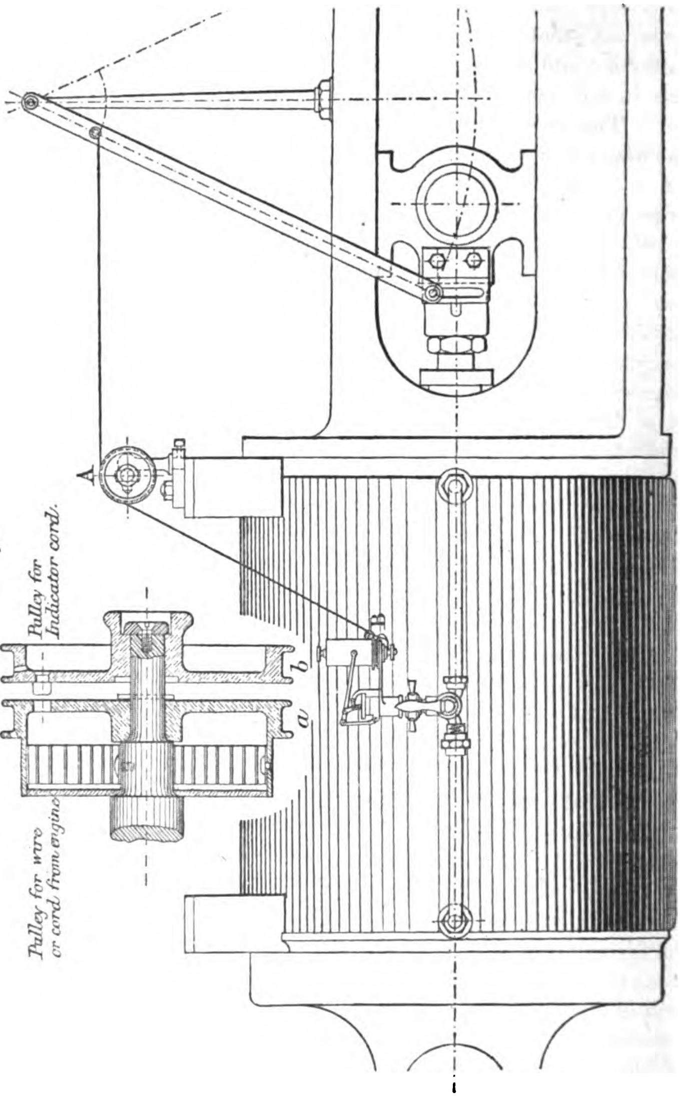
low-pressure cylinders. The next important difference was the adoption by the Author of the fluid brake. Professor Unwin had considered the fluid brake before he made his engine, but he did not see his way at the moment to make a fluid brake which would run with a constant load. The Author had accomplished that end, and no doubt the brake he had constructed was an extremely good brake to use on an engine. At the same time, he must a little protest against the comparison of fluid brakes with other brakes. The Author said he had had a good deal of experience with other brakes, and he proceeded to give a comparative account, which almost made it appear as if he had never seen a Prony brake reasonably well constructed. In the first place, he said that the Prony brakes required "constant observation and watching." Professor Unwin had a brake on a wheel 10 feet in diameter, which worked all through the day without attention or watching. It was said that a single engine could not be started without relieving the brake of its load; but this engine started with half the load, and he thought it would start with a full load. The Author said that such brakes were cumbersome, and were not easily adapted to measure greatly different powers. He did not know what cumbersomeness of the brake meant. It was like a fly-wheel on a shaft; it did not cumber him that he knew of, nor the engine. No doubt the fluid brake had a greater range of power than the solid brake; that was, it might be worked to a smaller fraction of the maximum load. That was an advantage, but not an enormous one. He could get his own brake down to a small fraction of the maximum load, and by having a couple of brake straps could reduce the load as he pleased. It was a little more troublesome, in the few cases where a small power had to be measured, but he did not recognize that any better result could be obtained from the fluid brake or a more accurate one than could be had, with a little trouble, from the solid brake. The Author had shown an indicator gear as a new gear. Professor Unwin remembered having the pleasure, about two or three years ago, of showing to the Author on the Guilds engine a gear which was identical with the one represented, except that there was a slight difference of construction, which gave it a little advantage in neatness. Instead of the long spring adopted by the Author, keeping the cord from the engine tight, he had a spiral spring inside a small 3-inch pulley. A second pulley alongside took the cord from the indicator. By a touch, one pulley could be put in or out of gear with the other pulley; and, on the whole, that made an arrangement more easily used by the student, and in which he was least

Professor Unwin. likely to put any straining action on the indicator. *Figs.* 2 showed the indicator gear mentioned. At A were two pulleys,

Figs. 2.



shown in section on a larger scale (half-size). One of these pulleys, *a*, was permanently attached to the rocking-lever on the engine by a wire or cord kept tight by a spiral clock-spring

Professor Unwin.

inside the pulley. The other pulley, *b*, was attached by a cord to the indicator B. The pulleys were on a universal joint, so that they were easily placed in the plane of the two free parts of the cords. A steel pin on pulley *b* fitted a hole in pulley *a*. Hence pulley *b* could be put into gear with pulley *a*, or pulled out of gear in a moment. When out of gear the indicator barrel was at rest. The arrangement shown was for one indicator. The engine was also fitted with cocks for using two indicators simultaneously, one indicator at each end of the cylinder. But with a sufficiently large pipe no difference was found in the diagrams whether one or two indicators were used. The results had, during the past four years, been systematically reduced in almost the same way as at the Owens College. The diagrams had always been drawn out in that way, with one very simple difference, namely, that a mean diagram was obtained with the clearance spaces shown. The diagrams were distant from the vertical axis of the co-ordinates by a distance which represented the clearance space; and then separate saturation curves were drawn, one for each diagram, leaving the diagram in that shape. The Author drew an ideal compression curve, and then moved back the diagrams until the compression curve came to the vertical axis of the co-ordinates. It was a matter of small importance. He thought that when the clearance spaces were left in the diagram rather more was shown, and rather fewer assumptions were made, and it lent itself better to adding to the diagram the rectangles, showing the heat exchange with the cylinder walls. He mentioned that, partly because he had been working in the same direction as the Author for some time, and for the credit of his Institution he did not like to think that it had been altogether outdone. He might add that the diagrams he obtained were almost identical with the high-pressure and the intermediate cylinder diagrams. There was no third cylinder in the Guilds engine, and therefore not quite as great re-evaporation; but when the jacket was in full action, a low-pressure diagram was obtained just touching the saturation curve in the best cases, or slightly off it in the others. He had for some time noticed how very large the jacket condensation was. In trying the Worthington engine at the Hampton Water-Works in conjunction with Mr. Mair-Rumley, from 13 to 16 per cent. of the whole of the steam used was condensed in the jackets. In the Guilds engine the amount of condensation was often 12 per cent., the difference in the two cases being that there was no jacket on the receiver between the cylinders, whereas in the Worthington engine, at Hampton, there was a jacket on the intermediate receiver. The

Professor Unwin. Author got still larger condensation from the jackets of the Owens College engine. It was rather remarkable that it was worth while throwing away from one-fourth to one-fifth of the steam, in order to keep the cylinder warm. He had looked with interest at the theoretical considerations on the action of the jackets on the cylinder submitted by the Author, who had taken a new line in considering merely what amount of heat supplied from the jackets was necessary to re-evaporate all the water produced by adiabatic expansion. It rather seemed that, in the numerical figures, the Author overlooked the fact that the whole heat must be given to the steam during a half of the revolution. He might be wrong, but from the figures in the Paper it appeared that it was so, and that the difference of temperature which the Author had given required to be somewhat greater. The Author neglected entirely what he believed in many engines was an important thing, namely, the percentage of priming water. He did not think it was ever absolutely absent, and suspected that, in a good many cases, it was an important factor in cylinder condensation. Then the mean temperatures, and the total quantity of heat transmitted to the steam were dealt with. It must be remembered that in order to prevent condensation on the cylinder walls, their temperature must be at every point of the stroke higher than the temperature of the steam, and that again would introduce a correction into the numerical result. The extraordinary cumulative effect due to the presence of water on the cylinder walls could not be more strikingly shown than by the very large black patches on the indicator diagrams for the case of no jackets.

Mr. Beaumont. Mr. W. W. Beaumont considered the paragraph relating to "trials without jackets" (p. 176) somewhat obscure. He understood, however, that it meant trials without jackets round the cylinders and the cylinder covers; but still with the jackets at work round the steam-pipes or the receivers. The question that occurred to him was this: the Author stated that the steam was admitted into the low-pressure cylinder as dry saturated steam, carrying into the cylinder the total heat of evaporation from the temperature of the condenser at the temperature of admission, and that it carried this heat to the condenser, less the heat-equivalent of the indicated work done in the cylinder. Was it right in that case to assume that the whole of the heat-equivalent of the work done should be deducted, or only that part of the work-equivalent which represented the expansion part of the stroke? It appeared that the receiver was really acting as a boiler, and that, instead of deducting from the heat carried away

into the condenser the whole of the work represented by the whole of the stroke, only that part represented by the expansion part of the stroke should be deducted, because steam was actually evaporated so as to suit the assumption that perfectly dry steam entered the cylinder—evaporated in that vessel just the same as if it were a boiler. He thought, therefore, that the heat-equivalent of the work done during the admission part of the stroke should not be taken into consideration as a deduction from the heat passing into the condenser; in other words, that the $p\,v$ part of the stroke should be deducted. That would slightly alter the expression given on p. 176 of the Paper, which would become Mr. Beaumont.

$$\frac{H_1 - h_3}{772} - \left(\frac{(\text{I.HP.} \times 42 \cdot 7) - \frac{p\,v}{772}}{\text{lbs. per minute from the hot-well}}\right).$$

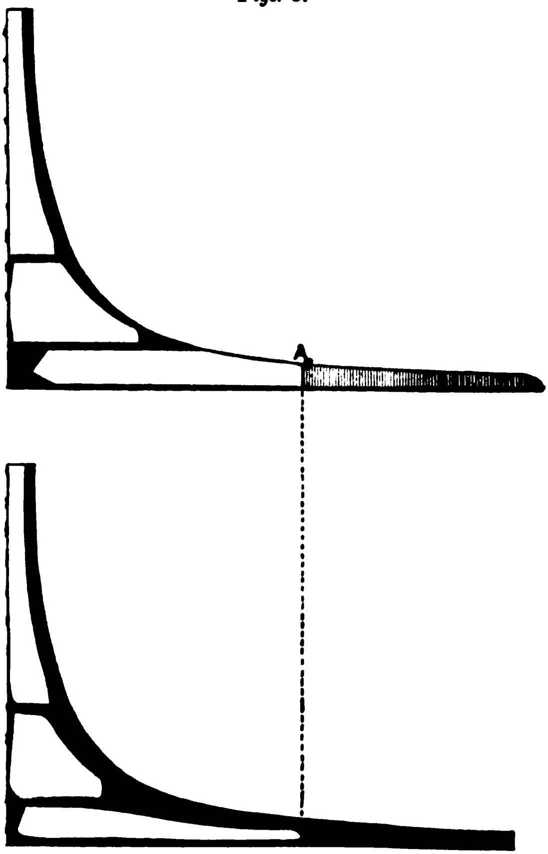
If that was not deducted he found that the equivalent in heat-units of that part was very nearly the heat-equivalent which the Author said in Table II was in excess, namely, 60 units. It made rather more than the 60 units, and less heat should be accounted for in the observed than in the calculated figures. The next point was, that the Author, in the arrangement shown (he mentioned this altogether apart from the propriety of his design), used high-pressure steam to evaporate water from which he got low-pressure steam. It was obvious that there must be a loss in doing that. If the paragraph, p. 176, was taken to mean that the trials really were without jackets altogether, without jackets round the pipe as well as round the cylinder, then, of course, the same correction would be true, inasmuch as it would not be the total heat of evaporation that would have to be taken into consideration, but the heat of evaporation under constant volume only. Leaving that part of the subject, though much might be said upon it, he wished to refer to p. 167, in which the Author spoke of a different kind of brake. He gave categorically his reasons for adopting the new instead of the older form of brake. Firstly, he said that such brakes required constant observation and watching; secondly, that a single engine could not be started without relieving the load; and thirdly, that brakes were cumbersome and not easily adapted to measure greatly different powers. With reference to these three points, it was fairly shown in the Paper that Mr. Beaumont had the honour of presenting to the Institution last session, that friction-brakes not only could be, but had been used, for trials of engines extending over greater periods than any of the trials mentioned

Mr. Beaumont. in connection with this engine; that engines could be started without relieving the load, and that the variation in the position of the suspended load need not be very great. Taking the last point first, he might recall attention to the brake known as the Balk brake, used for many years by Messrs. Ransome, and for engines working at very different powers. That brake could be set so that it should be run at least an hour at a time with the weight in the scale-pan, not moving more than $\frac{3}{4}$ inch, less the diameter of the pin that went into a slot of that width. With that brake the work upon the engine, or that the engine was doing, could be read off direct at any time, and the brake was run without water. Another and a better brake for varying loads, and needing perhaps even less attention, was one used by Mr. Halpin and others, in which there was a channelled fly-wheel with water running into it. The water simply ran into it and evaporated. If the wheel was kept sufficiently cool, that brake might run for almost any length of time without more attention than the one man driving and stoking the engine could give it. The variation in the level of the load was very little indeed. With regard to that variation, he noticed that the Author had shown in the illustration something very much like a dash-pot, and above that again, a spring, and he said the danger of such an arrangement had been carefully considered. This was with reference to the water-brake. He did not say what the precautions were, but he supposed they took the form of a dash-pot. If a dash-pot were used with either the Balk brake, or the water-channelled wheel-brake, or the rope-brake on the water-channelled wheel, all the results could be as easily, as economically and as accurately obtained as with this water-brake, and with a smaller number of pipes, water-connections and so on. Pipes and water-connections, however, did not seem to frighten any one concerned with the engine shown, so that perhaps they would not be looked upon as an objection. He thought that those three paragraphs might be answered therefore with at least a qualified denial. In conclusion, he wished to say that this arrangement of engines might have some advantages for experimental purposes; but the question was, whether those advantages were not obtained at the cost of great disadvantages.

Mr. Bodmer. Mr. G. R. Bodmer said it was superfluous for him to congratulate the Author on his very instructive Paper, since its value was obvious to all interested in the theory of the steam-engine. It seemed, however, rather a pity that, while making a new departure with regard to the design of the engine, the Author did not go a step further and jacket the piston. It was attended by some

practical inconvenience, but there was no very great difficulty about it, and it would be an interesting experiment. With respect to the trials and their results, it was rather to be regretted that the engines were allowed to run at different speeds, because it prevented the conclusions drawn from the experiments being directly applied to ordinary triple-expansion engines. For Mr. Bodmer

Figs. 3.



instance, when the low-pressure engine ran at a higher speed than the high-pressure one, it was equivalent to having a larger low-pressure cylinder, viz., to having a greater amount of expansion than was indicated by the cylinder-volume. It was obvious that in an ordinary engine it was impossible to vary the final cylinder-volume, and, with a given cut-off, the expansion ratio

Mr. Bodmer. was fixed. On that account it would be wrong to infer that the same advantage could be secured by jacketing an ordinary triple-expansion engine or compound engine as the Author had been able to obtain by jacketing his engine. To explain his remarks he had prepared *Figs. 3*, from the Author's illustrations. The lower diagram represented the experiments with the cylinders unjacketed; the upper diagram represented the corresponding experiments with cylinders jacketed. Taking the lower *Fig.* to represent the diagram of an ordinary unjacketed triple-expansion engine (the length of the diagram corresponding to the stroke of the low-pressure cylinder), then, if that steam-engine were jacketed, the volume of the low-pressure cylinder could not be increased or treated in a way that was equivalent to increasing it, by allowing it to run at a greater speed than the high-pressure part of the engine; therefore, the advantage obtained from jacketing that engine would be represented, not by the whole of the upper diagram, but only by the white portion; and, as compared with the Author's results, the whole advantage represented by the shaded portion of the diagram was lost, being the equivalent of the increased speed of the low-pressure, as compared with the high-pressure engine. With this portion of the diagram cut off, it was evident the advantage obtained by jacketing was much diminished. Nevertheless, the Author's experiments were extremely interesting, and tended to show that, in order to obtain the full advantage from jacketing an engine, the volume of the low-pressure cylinder must be made greater than if the engine were unjacketed, assuming a given cut-off in the high-pressure cylinder. Coming to the question of the action of the jackets, the Author assumed that heat actually passed through the walls of the cylinder from the steam in the jacket to the steam expanding in the cylinder, and attributed, at any rate, part of the beneficial action of the jacket to the passage of such heat. The figures appeared to a great extent to contradict this view, and Mr. Bodmer had prepared a "Supplementary Table," recapitulating a few of the Author's figures, and also giving some ratios calculated from them. Before referring to that Table he might mention that recent experiments had shown, notably those of Mr. Willans, and also the Author's trials with the unjacketed engine recorded in Table IV, that it was not essential to re-evaporation that the cylinder should be jacketed; but that re-evaporation took place in an unjacketed cylinder to a certain extent. The necessary heat, of course, came from that previously absorbed by the metal during the admission period. Line III of the Supplementary Table gave

Mr. Bodmer.

SUPPLEMENTARY TABLE.

—	——	44	41	33	35	56	40
I [44]	T. U. received as dry steam per minute . .	6,710	8,874	10,700	12,812	14,154	19,303
II [47]	T. U. received from the jackets, &c., per minute	2,337	1,390	3,072	1,643	3,325	2,225
III	Ratio of heat received from jackets to heat received as dry steam per cent.	34·8	15·7	28·7	12·8	23·5	11·5
IV	Excess of heat received by jacketed as compared with unjacketed engine, per cent. . .	16·5	..	14·0	..	10·8	
V [36]	Thermal efficiency . .	0·185	0·141	0·192	0·153	0·194	0·155
VI	Relative increase of efficiency due to cylinder jacket, per cent.	31·2	..	25·5	..	25·1	
VII	Ratio of heat lost by radiation to heat received as dry steam, per cent.	18·3	..	13·0	..	8·3	

the ratio of heat received from the jackets to that received as dry steam, and he had placed the results of corresponding experiments with engines jacketed and unjacketed side by side. For instance, column 44 referred to a series of trials with jacketed cylinders; 41 to the corresponding series with unjacketed cylinders. Taking the first two columns, for the jacketed engine the percentage was 34·8, and for the unjacketed 15·7. The 15·7 represented heat received only from the receiver jackets, and, assuming the ratio of the heat lost in the receiver jacket to be the same in both sets of trials, the proportion of heat given off by the cylinder jackets would be represented by the difference between 34·8 and 15·7. Line IV gave in percentage the excess of heat received by the jacketed as compared with unjacketed engines. That was for the first two series of trials (44 and 41), 16·5, for the second (33 and 35), 14·0, and for the third (56 and 40), 10·8 per cent. This was the heat actually given off in one way or another by the cylinder jackets as distinct from the receiver jackets, and owing, presumably, to the expenditure of that heat the increased efficiency represented by line VI was due. From this it appeared that for an expenditure of heat equivalent to 16·5 an increase of efficiency equal to 31·2 per cent. was obtained. That of itself was sufficient to show that only a portion of the apparent advantage secured came from the heat passing through the walls. To arrive at the proportion of heat actually transferred from the steam in the

Mr. Bodmer. cylinder jackets to the working steam, the heat lost by radiation must be deducted from the total expenditure in the cylinder jackets. The Author had not separated the loss by radiation in the receiver jackets from that in the cylinder jackets, and consequently Mr. Bodmer was unable to arrive with accuracy at the latter quantity. So far as could be judged from the illustrations accompanying the Paper, the ratio of the surface from which radiation took place for the cylinder jackets to the total radiating surface was as 1 to 3, and assuming this to be correct, an estimate could easily be formed of the quantity passing through the walls, which would be less by from 25 to 30 per cent. than the values given in line IV. As a matter of fact it might not be superfluous to point out, that, on thermo-dynamic principles, it was impossible any improvement in efficiency could result from an increase in the work done, due directly to the transfer of heat from the steam in the cylinder jackets to the steam working in the cylinder, because heat communicated in such a manner was utilized even less effectively than the heat introduced with the steam admitted to the cylinder. From this it was obvious that the whole of the advantage gained by the use of the cylinder jackets was a consequence of the restoration of heat absorbed, previous to cut-off, by the cylinder walls; this restoration took place partially in an unjacketed engine, but was rendered more complete by the action of the jacket in preventing recondensation during the admission period in the intermediate and low-pressure cylinders. The best of all would be to prevent initial condensation in the high-pressure cylinder, where the steam was of most value. It was to be regretted that the Author had not stated the proportion of steam condensed at various points of the stroke in the trials with jackets, in the same way as this had been done in Table IV for the trials without jackets. On p. 184 the Author said: "If the walls of the cylinders are maintained at the temperature of the initial steam, the expanding steam will absorb heat. This heat must pass through the walls; and as heat only flows through metal down the gradient of temperature, the temperature on the outside must be greater than that on the inside." Now this statement, he thought, was at variance with known facts. The heat absorbed by the expanding steam did not necessarily pass through the walls. In a cylinder without a jacket, the temperature of the walls after cut-off was lower than the temperature of the initial steam, and yet experiments had clearly shown that the expanding steam absorbed heat, and re-evaporation took place. It was in the main not a question of the passage of heat through the walls, but, as already indicated, of a

restoration of heat to the steam from which it had been taken during the admission period. The Author's calculation, of the amount of heat per lb. of steam necessary to prevent supersaturation, was not applicable to the conditions obtaining in his engine; it would only be correct if the whole of the steam, at the moment when expansion commenced, were quite dry and were maintained in this condition throughout. The quantity of heat required to prevent the condensation otherwise accompanying work performed (in a non-conducting cylinder), depended on the proportion of water initially present. If about 50 per cent. of water were present, no heat would be required to prevent further condensation, the saturation curve for the dry portion of the working mixture (steam and water) corresponding with the adiabatic curve for the whole of the mixture. The only correct method was to calculate, from the total measured work done during expansion on one side of the piston and the increase (or decrease) in the internal heat, the quantity of heat communicated during expansion, and compare this with the heat given up to the walls during admission. The difference between these two quantities would give the heat which must pass through the walls from the jacket-steam. Mr. Bodmer.

Mr. P. W. Willans said the subject was one which had long been of interest to him. He would refer in the first place to a paragraph in the Paper (p. 152), and then to two paragraphs in the abstract of the Paper (p. 195). "A systematic and experimental investigation of the steam-engine involves two sets of conditions, which, unless it be in a laboratory, can hardly exist together, namely, the time and attention of the scientific investigator, and the assistance of a considerable number of trained observers. In the engineering laboratory, these conditions should exist: the first being supplied by the permanent staff, and the second by the students as their training advances." "For this purpose, ordinary steam-engines, doing ordinary work, were about as good as ordinary animals in their ordinary occupation, were for subjects of physiological experiment. In certain particulars both could be accurately observed, as, for instance, how much coal or food was necessary during the performance of a particular operation; but to ascertain how all the separate organs were performing their several functions was impossible with an ordinary steam-engine, without subjecting it to a species of mutilation which left it about as fit to continue ordinary work as an animal that had been the subject of physiological study." "It was evident that the engines and apparatus for operating upon should be such, that each organ, Mr. Willans.

Mr. Willans. while similar to, and performing the part of, the corresponding organ in an ordinary engine, should be so arranged with respect to the other organs, as to admit of the manner in which it performed its part being completely gauged; and that this should be simultaneously with all the organs, both those corresponding to the ordinary engine and such special organs as should be introduced to admit of access to the others, so that the action of these latter might be accurately discounted." He had asked himself the question whether, what was practically stated in these paragraphs—that experimental investigations in connection with steam-engines could only be properly carried out in the laboratory, and on engines of special construction—was or was not true, and what advantages those working in a laboratory had over others? He had come to the conclusion that a man in the Author's position had one great advantage, namely, that he ought to be quite unbiassed in his work by any feeling as to whether it would come out well or not; and that was a position in which it was exceedingly difficult for men like himself to place themselves, because they were influenced every day by the feeling of competition, and by a desire to do better than others. The Author, however, was working under great disadvantages in other respects; he had only one engine, and although he might give it at the start as many organs as he pleased, yet he could not give it the organs which were not yet invented. He compared experiments on steam-engines with physiological experiments on animals, but there was this difference between animals and engines: that in their time at any rate, an animal was pretty much the same animal, for if the Author took a rabbit and went on experimenting for the next hundred years, he would still be able to get another rabbit with which to continue his experiments; but if he took an engine, the worst of it was, there was soon somebody else who had made a better engine, and evolution in the case of steam-engines being so rapid, it was impossible to make a laboratory engine which should for any long time together remain a representative one. However efficient such an engine might be now, it would soon be superseded, and the scientific investigator, with only one engine, would then be in about as good a position to settle points relating to steam-engines as the physiological experimenter would be to determine the speed of the next Derby winner, if the only animal available for experiment was a specimen of the ancient Eohippus. Then the maker of steam-engines had another advantage, although it might sometimes be thought a disadvantage, and that was, that when he had made an engine and said that it did so and so, somebody else frequently

said it did not. He did not say that this would always seem an advantage at the time; but in the long run it certainly was an advantage to the experimenter to have to prove his case and his figures to the satisfaction of an outsider. He had read the Paper carefully, checking it figure by figure, so far as the data given would allow, because, first of all, he wished to understand the methods on which the Author had been working. Being about to start similar trials, he wished to get the benefit of his ideas, and therefore had gone more carefully into the matter than he would have done at any other time. He regretted, however, to say that he had not been favourably impressed with many of the Author's methods, and he also totally disagreed with his choice of the standard with which to compare the work of his engine. He proposed, therefore, to follow the Author through his various methods and calculations, and the data which he would make use of were the following:— Mr. Willans.

Table I, line 56 .	lbs. per hour of mixed feed to boiler, neglecting leakage.
" " 37 .	lbs. of water discharged from hot-well per minute.
" " 46 .	lbs. per minute of water from the jackets, &c.
" " 27 .	Total I.HP.
" " 5 .	Initial temperature calculated from pressure in 1st receiver.
" " 6 .	Final temperature calculated from condenser-pressure.

Now with respect to these data, and the methods by which they had been obtained, he wished to offer a few criticisms. The mixed feed per hour (line 56) was the sum of water discharged from the hot-well, and of that discharged from the jackets. Neither of these quantities had been weighed as a whole, and the only reason he could see for the method adopted—namely, weighing 100 lbs. at a time in the case of the hot-well water, and noting the rate at which the water rose in the separator for a portion of the time in the case of the jacket-water—was that an engine trial and boiler trial were made together, and that the Author wished to get the best possible results in both in order to beat the record. This, in the abstract of the Paper, he claimed to have done, and he must not be surprised, if on that account his figures were scrutinized closely, and his methods criticised where there was occasion. The Author had stated that there was a difference in most cases of from 5 per cent. to 10 per cent. between the water supplied to the boiler and that discharged from the hot-well. He did not think that any experimenter was

Mr. Willans. justified, when he knew of such a discrepancy, and knew also that the boiler was "practically tight," in taking the discharge from the hot-well for the purpose of calculating his results; he could not believe that there was any law of nature by which differences of 10 per cent. between the two could be accounted for. Only recently, in a Paper by Mr. Thornycroft,[1] an account was given of several trials of a torpedo-boat, and in these the difference between feed-water and hot-well discharge was always less than 1 per cent., after allowing for steam used by a steering engine. Why then should there be such a difference in this case? And why, if there was such a difference, was it taken as proved that none of this steam passed through the engine? The Author took no account of what was usually present, namely, a little vapour from the hot-well, and the same from the piston-rods and glands (there were nine rods in all, including the valve-rods); but he jumped to the conclusion that the engine had nothing to do with this 5 per cent. or 10 per cent. Mr. Willans contended that this was not right, and he felt sure that if any other engineer gave such figures about his own engines, they would be most severely criticised. Mr. Willans had given, in all cases, in his Paper,[2] the total feed-water pumped into the boiler during the period of the experiment, the water being drawn from a large tank mounted on a weighing-machine (entailing one reading only for the whole time), and he had based all his figures upon the total so ascertained. Would the Author think it fair of him if he deducted 5 to 10 per cent. from the total, because the Professor found that such a difference generally existed? He also thought that the figures for feed-water for each trial might have been supplied, seeing that there was a doubt in the matter. Next, with respect to the figures for jacket-water, Table I, line 46. The Author explained that these were arrived at by "measuring the rate of discharge from the jackets every half-hour." The cock at the bottom of the separator was, as he understood it, shut by the student every half-hour, and the rate at which the water rose in the gauge-glass on the separator was noted. Now the dimensions of the separator were such that not more than 20 or 25 lbs. of water could be allowed to collect in it, so that, assuming absolute accuracy in the observations taken every half-hour, about 40 or 50 lbs. of water per hour would be measured; while 237 lbs. in the case of trial 56 was assumed to be the quantity passing through per hour; if therefore he understood

[1] Minutes of Proceedings Inst. C.E., vol. xcix. p. 41.
[2] *Ibid.*, vol. xciii. p. 128.

the Author correctly, only one-fifth of the jacket-water had in this trial gone through even a form of measurement. Surely it would have been a more certain plan to have made the engine or boiler trials independently, and to have weighed accurately the jacket-water for the entire trials. Next, as to the total indicated HP., an elementary difficulty was that the dimensions necessary for re-calculating the indicated power were not given. On p. 153 the dimensions of the engine were stated to be "somewhat as follow." He did not consider that "somewhat as follow" was quite near enough. A dimension was also missing, for, in calculating the power, however interesting the diameter of crank-shaft might be, it was not so necessary as the diameter of the piston-rod, in getting at the net area of the cylinders, and he trusted it had not been omitted from the calculations as well as from the table of dimensions. Then, if he understood the Author correctly, the mean pressure had been calculated by measuring the pressure on the diagrams at ten breadths, and taking the mean of these as the mean pressure. "These results have been several times checked by a planimeter without establishing any sensible difference." He wished to point out that the measurement could only be accurately done by means of a planimeter, for if measurements by ordinates were taken in the middle of ten equal breadths, in the case of the jacketed low-pressure diagrams, Plate 4, Fig. 14, there would be, for trial 33, a result at least 5 per cent. in excess of that given by the planimeter; this was on account of the late admission and the position which the first measurement happened to take with reference to the corners missing from the diagram. The same remark applied in a varying extent to all the diagrams; he thought it was impossible to impress the fact too strongly on the minds of students, that the measurement of indicated power by ordinates was an inexact and uncertain method. Mr. Willans.

In order to ascertain the thermo-dynamic efficiency of the engine, it was necessary to ascertain the higher and the lower limits between which the engine worked. Here again he was met by a difficulty, for the temperatures given in Table I, line 54, as the temperatures of the boiler, were the same throughout all the six trials, namely, 383° Fahrenheit, whereas the mean absolute pressure in the boiler varied from 200 lbs. in trial 44 to 207 lbs. in trial 56. This would not make much difference to the efficiency, but it had made it a little difficult to follow the Author's calculations, the temperature being the starting-point. In going through the Paper casually, his attention had been drawn to the very high thermal efficiency which the Author gave for one of the trials,

Mr. Willans.

—	Number of trial
A	Lbs. of mixed feed per hour (neglecting leak)—Table I, line 56
B	Total indicated HP.—Table I, line 27
C	Water per indicated HP. per hour, neglecting leak, but otherwise as usually reckoned, *i.e.* hot-well and jackets
D	Water per indicated HP.—Table I, line 70
E	Measured efficiency—Table III, line 9
F	Thermal efficiency as usually reckoned—Table I, $\frac{\text{line 34}}{\text{line 48}}$
G	Initial and final temperatures, Fahrenheit—$\frac{T^1 \text{ steam-chest}}{T^2 \text{ condenser}}$
H	Cost of 1 lb. of steam in thermal-units, water raised from condenser temperature to steam-chest temperature and evaporated at steam-chest temperature
I	Lbs. per minute feed from hot-well—Table I, line 37
J	Thermal units received per minute by engine in weight of steam answering to hot-well discharge
K	Thermal units given up per lb. of steam condensed in jackets at boiler temperature
L	Lbs. of jacket-water per minute—Table I, line 46
M	Thermal units received by engine per minute from jacket-steam
N	Total heat per minute (feed and jackets)
O	Heat utilized—Table I, line 34
P	Absolute efficiency—$\frac{\text{line O}}{\text{line N}}$

Mr. Willans.

44	33	56	41	35	40
516·2	793·2	977·4	562·8	805·2	1,213·2
33·23	55·76	72·1	30·92	48·51	73·87
15·53	14·23	13·56	18·20	16·60	16·42
14·1	13·2	12·68	17·3	16·0	15·9
18·5	19·2	19·4	13·8	15·3	15·5
15·71	17·31	17·65	12·91	14·35	14·67
381·15 / 115·9	380·7 / 120·35	382·8 / 129·8	383·2 / 110·8	383·6 / 122·4	382·0 / 134·6
1,108·9	1,104·3	1,095·5	1,114·6	1,103·0	1,090·5
5·83	9·58	12·34	7·73	11·47	17·58
6,464·8	10,579·2	13,518·5	8,615·8	12,651·4	19,171
843·43	843·1	841·29	841·89	841·59	842·5
2·77	3·64	3·95	1·65	1·95	2·64
2,336	3,068	3,323	1,389	1,641	2,224
8,801	13,648	16,840	10,005	14,292	21,395
1,421·0	2,384·0	3,085·0	1,323·0	2,074·0	3,158·0
16·14	17·46	18·31	13·22	14·51	14·76

Mr. Willans.

—	Number of trial
Q	Theoretical efficiency of Carnot cycle: heat utilized per lb. of steam = latent heat at A $\times \frac{A - B}{A}$
R	Theoretical efficiency of Clausius perfect engine: heat utilized per lb. of steam = $(1{,}438 - 0{\cdot}7\,A)\frac{A - B}{A} + (A - B) - B \log_e \frac{A}{B}$
S	Theoretical efficiency of jacketed engine: heat utilized per lb. of steam $= 1{,}438 \log_e \frac{A}{B} - 0{\cdot}7\,(A - B)$
T	Author's theoretical efficiency—Table III, line 8
U	Percentage of theoretical efficiency of Carnot cycle—$\frac{\text{line P}}{\text{line Q}}$
V	Percentage of theoretical efficiency of Clausius perfect steam-engine $-\frac{\text{line P}}{\text{line R}}$
W	Percentage of theoretical efficiency of Rankine's jacketed engine—$\frac{\text{line P}}{\text{line S}}$
X	Author's percentage of theoretical efficiency—Table III, line 10
Y	Feed-water per indicated HP. hour required by Clausius perfect engine
Z	Feed-water per indicated HP. hour which would be raised from T_2 to T_1 and evaporated at T_1 by total heat per minute, line N $= \frac{\text{line N} \times 60}{\text{line H} \times \text{line B}}$
..	Efficiency $\frac{\text{line Y}}{\text{line Z}}$

In the above Table T_1 and T_2 are temperature Fahrenheit scale,

Mr. Willans.

44	33	56	41	35	40
31·49	30·93	29·98	32·26	30·92	29·34
28·33	27·86	27·06	28·96	27·8	26·52
25·8	25·4	24·7	26·3	25·4	24·3
23·3	23·2	22·7	23·3	23·2	22·4
51·2	56·4	61·0	40·9	46·9	50·3
56·9	62·67	67·6	45·6	52·1	55·66
62·5	68·7	74·1	50·2	57·1	60·7
79·4	82·6	85·4	59·2	65·9	69·4
8·17	8·33	8·65	7·94	8·35	8·86
14·33	13·29	12·79	17·41	16·02	15·93
56·9	62·67	67·6	45·6	52·1	55·66

and A and B the equivalent temperature Fahrenheit absolute.

Mr. Willans 19·4 per cent. in one case (in the body of the Paper 0·20 was named, p. 174). The percentage of theoretical efficiency actually obtained in this case (trial 56) was given as 85·4. In non-condensing engine trials he had been accustomed to get as much as 82 per cent. himself; but in such condensing engine trials as he had made it was very much below that, and he had not hitherto seen, in any recorded experiments, figures at all approaching 85 per cent.; he had, therefore, from the Author's data named above, re-calculated all his figures as to efficiency in the standard methods, and the results of these calculations were given in the preceding Table, pp. 218–221.

In this Table, lines A, B, D, E, I, L, O, T, and X were simply transferred from the Author's Table for comparison. The figures in line C were obtained by dividing those for mixed feed in line A by those for total indicated HP. in line B. The figures in line A were those which took no account of the leak to which reference had already been made, and the calculations based on these figures, therefore, gave the Author the benefit of the doubt, as he did himself. The figures in line C were directly comparable with many of the figures given for water per indicated HP. in other cases of jacketed engines, in Mr. Mair-Rumley's among others. It was not everybody who had the advantage of being able to drain the water back into the boilers in the admirable manner adopted by the Author, and frequently the jacket-water was allowed to drain into the hot-well, and was pumped back into the boiler as part of the feed. The Author's figures, "lbs. per indicated HP. of feed-water to supply as dry steam the total heat for engines," were given in line D for comparison, and it should be understood that these figures did not represent the total steam passing from the boiler in the shape of steam and returning as water, but such an amount of steam as would be evaporated by the heat abstracted from the total steam passing through the engine and through the jackets. Undoubtedly the Professor was justified, in his case, in looking at the matter in this manner; but it was evident that certain conditions were necessary as to the relative levels of engines and boiler in order to permit the jacket-water so to drain back. In line E were stated the Author's figures for thermal efficiency, the only figures given in the Paper for the absolute efficiency of the engine. The wording of that line was rather curious, "thermal efficiency as given by heat discharged in condensing water"; but he was surprised to find it stated, in the abstract of the Paper, though not distinctly in the Paper itself, that it did not include radiation; and no doubt many of the members had not realized

Mr. Willans.

that radiation was excluded. The heat-units lost by radiation in some cases amounted to a very large proportion of the heat-equivalent of the indicated power. In the case of trial 44, for instance, the loss by radiation was given as 1,227 thermal units, while the indicated power was equivalent to 1,421 thermal units. If radiation was excluded from such trials, the work done might almost as well be neglected. He had re-calculated that line by dividing the figures in line 34, which gave the thermal units discharged as indicated HP., by the figures in line 48, which gave the total heat supplied to the engine. The results were supplied in line F, and were those which were usually taken as representing the absolute efficiency of a heat-engine, namely, $\frac{\text{heat utilized}}{\text{heat supplied}}$. The Author was trying jacketed against unjacketed engines, and it was obvious that the radiation in the former must be greater than in the latter. In excluding the radiation, he omitted one of the most important factors in the comparison between the two engines; the effect of the omission being greater in the case of the jacketed than in the unjacketed engine, it gave the jacketed engine an unfair advantage. Mr. Willans was not in any way concerned to defend unjacketed against jacketed engines; he only said that in this case it was not a fair trial.

What the Author called thermal efficiency was not, therefore, what engineers were in the habit of calling absolute efficiency, and he thought he should show also, that the standard with which the Author had compared his results, was not the one upon which engineers ought to look as representing the highest theoretical efficiency. He had recalculated the efficiency of the engine in the various trials, taking as the initial temperature that answering to the pressure in what the Author called the first receiver, the steam-chest of the high-pressure engine, and as the final temperature, that answering to the condenser back-pressure. These temperatures were, in the case of trial 56, 382°·8 and 129°·8 Fahrenheit. The feed-water from the hot-well might be assumed to be raised in the boiler from 129°·8 to 382°·8, and to be evaporated at the latter temperature; if it happened to leave the hot-well at a lower temperature than 129°·8 Fahrenheit (the temperature answering to the condenser back-pressure), that was a circumstance which ought not to tell against the engine as an engine, for the feed-water could, theoretically at least, be raised by the exhaust-steam to the temperature of the latter, but that was the highest temperature to which the feed-water could be raised by waste heat from the engine

Mr. Willans. itself. He therefore assumed that each lb. of water, leaving the hot-well, represented an expenditure of heat equivalent to that required to raise it from the temperature answering to the condenser back-pressure, to that answering to the pressure in the first receiver, plus the latent heat of evaporation at the latter temperature. In the case of trial 56, the expenditure of heat per lb. of hot-well discharge (line H) was 1,095·5 thermal units, and the lbs. discharged per minute (line L) were 12·34; thus the thermal units debited to the engine per minute on account of steam answering to the hot-well discharge were 13,518·5 thermal units (line J). In the case of the jacket-water only the latent heat was given up, and he therefore debited the engine with the latent heat of each lb. of steam condensed at boiler temperature; in the case of trial 50, the jacket-water (line L) amounted to 3·95 lbs. per minute, and the latent heat being 841·29 thermal units per lb., the heat debited to the engine on account of jacket-steam was 3,323 thermal units (line M). The total heat debited to the engine per minute, lines J and M, amounted to 16,841 thermal units (line N) = heat supplied. The heat utilized was the heat equivalent of the work done = 3,085 thermal units (line O). Line P gave the absolute efficiency of the engine, as calculated from the above figures, and it was, for trial 56, 18·31 per cent. All these calculations were based on the quantity of water proved to have passed through the engine, and did not include the leakage already mentioned.

The next question was as to the engine which should be taken as the standard of perfection. It had been a common thing to take the Carnot cycle, working between the same limits of temperature, as the standard; in this cycle all the heat was assumed to be received at the higher temperature, and the heat necessary to raise the condensed steam, from the lower to the higher temperature, was assumed to be supplied by the conversion of a part of the power generated into heat, by the process of compressing a portion of steam remaining in the cylinder. Not long ago he went very fully into this question,[1] and gave his reasons for not using the Carnot cycle as a standard. These reasons were mainly theoretical, but he thought there was one very strong practical reason why the Carnot cycle would never be carried out in practice, and this was that it would always be cheaper to heat the feed-water by the waste gases from the furnace. In order to heat the feed-water dynamically, some part, however small, of the power of the engine must be used, but, as the Author had shown in this case, the furnace

[1] Minutes of Proceedings Inst. C.E., vol. xcvi. p. 239.

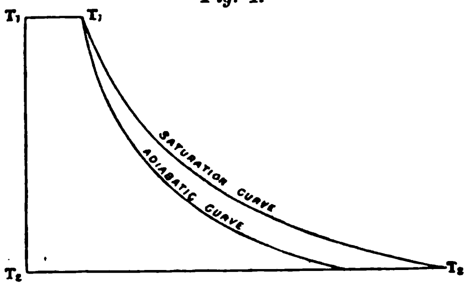
gases were always at hand for the purpose, and as their heat would otherwise be wasted, it was better to use it than any part of the power of the engine, however small that part might be. If, however, it was fitting in any case to compare the absolute efficiency of an engine with the absolute efficiency of the Carnot cycle, it would be so in this case, where in some trials almost 33 per cent. of the steam passing through the engines and jackets passed through the latter. All the heat supplied to this jacket-steam was supplied at the higher temperature, and consequently the percentage of work due from it was greater than that due from the heat supplied to the hot-well water. Unfortunately, however, although the heat was supplied in the boiler at the higher temperature to the hot jacket-water, it was transmitted through the walls of the cylinder to the working fluid under very different conditions. Still, he thought it would be interesting to give in line Q the absolute efficiency of the Carnot cycle working between the same limits of temperature (line G). In the case of trial 56 this efficiency was 29·9 per cent. as compared with 18·31, the absolute efficiency of the actual engine. Line U gave the percentage of the theoretical efficiency of the Carnot cycle reached by the actual engine in trial 56, which was $\frac{18 \cdot 31}{29 \cdot 9}$, or 61·3 per cent. of the theoretical possibilities, taking that cycle as the standard. Mr. Willans.

Now putting on one side the Carnot cycle as an unattainable ideal, and for the practical reasons already given an undesirable ideal, he would next compare the efficiency of the actual engine, in trial 56, with the efficiency of the perfect steam-engine of Clausius; that was to say, he would compare the return from heat expended, with the return from 1 lb. of steam supplied to an engine in which there were no losses from passages, leaks, or cylinder-walls; in other words, an engine which took 1 lb. of steam into the cylinder at the higher temperature, expanded it adiabatically to the lower temperature, and expelled it at the lower temperature. It might be said that this was also an unattainable ideal, and in the sense that no engine would ever be made which absolutely came up to it, it was so. Still it represented the highest aim of the engineer, and it was being steadily approached. In certain classes of engines, certain classes of loss had been practically eliminated; for instance, in low-speed engines there was no appreciable loss from passages, and he himself had shown that, in a high-speed engine, it was possible to approach very closely indeed to the adiabatic curve. Under certain conditions this could be approached, for instance, within 5 per cent.; therefore he always took as his standard

Mr. Willans. the result from the practical but perfect engine of Clausius, and compared his results with it. Line R gave the theoretical return from such an engine always working between the limits of temperature given in line G. This return was, in the case of trial 56, 27·06 per cent. of the heat supplied, and comparing this return with that from the actual engine, which had been already shown to be 18·31 per cent. of the heat supplied, he found that the relative efficiency of the Author's engine, as compared with the perfect steam-engine of Clausius, was 67·6 per cent. The Author, however, took as his standard an engine which gave a return of only 22·7 per cent. of the heat supplied to it, in the case of trial 56. He compared what he called "thermal efficiency" (which was arrived at by neglecting radiation, one of the most important factors in the case), with something that did not, to Mr. Willans, represent the "thermal" efficiency of any engine or cycle whatever.

It would be easier to follow his argument by reference to *Fig. 4*, which showed the work possible from 1 lb. of steam treated in different ways.

Fig. 4.



T_1 and T_2 were the temperatures between which the engine worked. The inner curve of expansion was the adiabatic expansion-curve for steam expanding from T_1 to T_2; not "a special adiabatic curve," as the Author said, but the adiabatic curve, for there was only one, if dry steam was supplied. The outer curve was the saturation-curve for 1 lb. of steam between T_1 and T_2. The inner line was the line which the indicator would trace if no heat was given off to the sides of the cylinder and none received from them. The outer line was what the indicator would trace if, by adding heat during expansion, the water necessarily formed was re-evaporated by heat received from the steam-jacket. The cost of the inner, or adiabatic diagram for a theoretically perfect steam-engine, was the cost of raising 1 lb. of water from T_2 to T_1, and converting it into steam at T_1. In the case of an engine

working between the same limits of temperature as those in trial 56, the cost was 1,055·5 thermal units (see line H). The area of the diagram, namely, the work done, was 297·4 thermal units, representing an efficiency of 27·06 per cent. as given in line R. The cost of the outer diagram was the cost of 1 lb. of steam as above, plus the cost of keeping it during expansion in the state of saturation. This latter added heat was given by the formula $1{,}438 \log_e \frac{A}{B} - (A - B)$, and was in the case of an engine working between the same limits of temperature as those in trial 56, 259·58 thermal units. The area of the diagram was represented by 335·5 thermal units, so that the return for heat expended was only 24·7 per cent. Thus, between the thermal limits in question the return from steam used in an engine expanding its steam adiabatically was 27·06 per cent. as compared with 24·7 per cent. in the case of the best possible jacketed engine. The cost of the saturation diagram was to the adiabatic as 1·23 to 1, while the return from it was only as 1·13 to 1; so that when the Author stated, that both in the case of the jacketed and unjacketed trials, he had compared the actual efficiencies with the highest theoretical efficiency between the same limits, and that he had calculated the theoretical efficiency as for saturated steam, it seemed to Mr. Willans to be a contradiction in terms. The work shown by the saturation diagram, compared with the cost of such a diagram, by no means represented the highest theoretical efficiency. The Author, however, appeared to think that it did, for in the abstract of the Paper he congratulated himself on the result in the following words: "Thus, in these trials, with steam at boiler-pressure in the jackets, low-pressure diagrams had been obtained, apparently for the first time, in which the curve of expansion coincided exactly with the curve for saturated steam." The fact was that jacketing was simply a compromise. It was effective in promoting economy in certain cases, because more was gained by preventing condensation than was lost by re-boiling the water formed during expansion, and using high-pressure to make low-pressure steam. But for comparison with the work performed, the standard should be the adiabatic diagram. In many diseases it was necessary to prescribe poisons; but after a doctor had prescribed, say arsenic, it would hardly be satisfactory to the patient's friends to be told that he was now a fair sample of a man poisoned by arsenic, even if the original disease had vanished. The question was how the patient's state compared with that of a healthy man. So with the Author's engine. The question was how far did it

Mr. Willans.

Mr. Willans. come short of the ideal perfection possible in a steam-engine; not how near was it to the comparatively sickly jacketed standard. Looking at the matter broadly, it seemed to Mr. Willans that the Author had increased the efficiencies in the various trials by omitting factors always of great importance, and in this case of especial importance, and that he had then compared these inflated results with a new standard for which there was no sound reason. The efficiency which the Author gave as 85·4 per cent. was, he considered, 67·6 per cent. These were the figures to which he wished to draw the attention of the meeting. It would be seen that the Author's figures for water per indicated HP., line D, agreed very closely with line Z calculated by him; and he presumed that these slight differences could be accounted for by differences in the temperatures taken as the higher and lower temperatures for ascertaining the cost of steam; but he thought the figures given by himself were those which would be taken by most engineers. He had given, in line S, the theoretical efficiency of the best jacketed engine working between the limits of temperature in the various trials; but even these efficiencies did not exactly correspond with the efficiencies which the Author had taken as a standard, which were given in line T. Evidently the area of the saturation diagram had not been taken in its fulness as the measure of work obtainable through the agency of 1 lb. of steam and the explanation was apparently found in a sentence which appeared in this connection, p. 181: "The area enclosed between the limits of pressure and volume . . . expresses in foot-lbs. the greatest possible amount of heat that can be converted into work through the agency of 1 lb. of steam maintained in a state of saturation between these limits." In fact the Author had compared his results, not with the whole area of the diagram for 1 lb. of steam maintained in a state of saturation between the limits T and T_2, but with that diagram shortened so as to correspond with the terminal pressure in his own experiments, that was, with a still lower standard than the jacketed engine; this was an interesting comparison for some purposes, but had no connection with what was now usually understood by the words thermal efficiency. If the standard was to be altered with the point of cut-off, a fire engine or a donkey-pump would be the most efficient engine in existence.

With respect to the general results of the trials, a point which had struck him very much was the small effect of the jackets on the missing quantity in the high-pressure cylinder. He should be glad to know whether the Author could give the figures for the cor

densation in the various cylinders in the case of the jacketed-engine trials, in the same way as he had given them for the unjacketed ones (Table IV). So far as could be judged from the diagrams, the effect of jacketing on the amount of the missing quantity in the high-pressure cylinder was very small. Was it possible that there was considerable leakage past the low-pressure and intermediate jackets? The mean temperature of the liners of the cylinders would probably be, in these cases, considerably below the temperature of the main casting of the cylinder when the engine was at work. Consequently the liners would be relatively less in diameter and shorter than when the engine was standing, and such leakage would be exceedingly difficult to detect, because the only way apparently of observing it would be when the covers were off and the engine standing, at which time the liners would be as hot as the cylinder. Mr. Bryan Donkin's recent experiments[1] showed that the cylinder wall varied in temperature with the steam inside, and in the case of an engine in which it did not so vary there could hardly be condensation as in this case. The Author had spoken of the mechanical efficiency of the engine as being rather low, and he had explained it by pointing to the large valves. These large valves no doubt took a good deal of driving, but on the other hand they were made large so as to have as small losses as possible from passage friction, and therefore there was probably a corresponding gain in the cost of the indicated power. If it were tried to obtain the last ounce of indicated work, it would very likely be got with a loss of real efficiency. The power lost in moving the valves, however, was not wholly lost, as it probably, in great part, reappeared as heat imparted to the steam. The Author had, he thought, lost sight of this in arriving at his heat-balance. In the case of trial 56 only 76·5 per cent. of the indicated power was converted into work, so that 23·5 per cent. was lost in friction. It was not unreasonable to suppose, he thought, that with these large valves the internal friction from them and from the glands and piston-rings accounted for a large portion of the total loss. Assuming that 15 per cent. of the work was consumed in internal friction in the case of trial 56, about 462 thermal units would have to be added to the radiation account, because the condensing water would include that amount of heat received from the indicated HP. wasted in friction, which heat would in Table I, line 35, be reckoned twice over unless 464 heat-units were transferred to the radiation account. Would the Author state why he was so anxious for the indicator Mr. Willans.

[1] Minutes of Proceedings Inst. C.E., vol. xcviii. p. 250.

Mr. Willans. to have a vertical position? He had added an otherwise unnecessary elbow in order to permit it to stand in this position; Mr. Willans preferred to place the indicator in a horizontal position on a vertical engine, and was not acquainted with any reason against such a position. With regard to all the methods of making the trials, they appeared to him to err on the side of complexity. The list of fittings, p. 160, was a truly formidable one, and was so different to the state of things in his own trials, where the boiler had only five fittings—a blow-off cock, a water gauge, a stop-valve, a safety-valve, and a feed check-valve—and only one steam-pipe with a joint at each end, that he should not be surprised at even greater discrepancies than those which had been found to exist. From the fact, however, mentioned on p. 174, that several trials could be made under similar conditions, the results not varying by more than 1 per cent., he concluded that the leak was a constant one, and this being so, it appeared extraordinary that it had not been located. Had the Author considered how serious a matter it was to send out fourteen students to make similar trials, all prepared to accept such discrepancies as inevitable and unaccountable?

He thought, in conclusion, that it might be interesting to compare the Author's results with a condensing trial of one of his own engines.[1] In this trial, which was not conducted under conditions favourable to the highest economy, but only for comparison with a trial made with the same number of expansions exhausting into the atmosphere, the consumption of steam calculated as feed-water pumped into the boiler was 15·2 lbs. per indicated HP.-hour. The mean admission pressure was 168 lbs. absolute, and the back pressure in the condenser 4·4 lbs.; he was sorry that he had not the steam pressure in the high-pressure steam-chest for exact comparison with the Author's trials, but he would take it at 5 lbs. higher than the mean admission pressure in the cylinder. The higher and lower temperatures were then 369°·5 Fahrenheit and 156°·7. The water theoretically required per indicated HP.-hour between these limits was 10·26 lbs., and the water actually used being 15·2 lbs., the thermal efficiency was 67·5, or almost exactly the same figure as that found in the Author's best trial, if the calculation was made in the same manner. It would be observed, therefore, that the thermal efficiency of the Author's engine could hardly be said to be unprecedented, as even an unjacketed engine worked with an eight-fold expansion had given the same thermal efficiency, when

[1] Minutes of Proceedings Inst. C.E., vol. xcvi. p. 255.

Mr. Willans. calculated in exactly the same way, except that the Author's figures were based on water coming out of the hot-well, and on jacket-water estimated rather than measured, while his own were for water pumped into the boiler. He regretted that he was as yet unable to give figures for condensing-engines, using steam of as high a pressure as that used in the Owens College trials, but he hoped to do so shortly.

The Author's figures for unjacketed trials were absolutely worse than his own, although the pressure used was greater and the vacuum better, being 17·4 lbs., 16·0 lbs., and 15·9 lbs., for steam of 200 lbs. pressure and calculated from the hot-well discharge, against 15·2 lbs. for steam of 168 lbs. pressure and calculated from the feed-water. The Owens College engine had been worked, so far as he could ascertain from the diagrams, with a ratio of expansion in the jacketed trials of 20 to 25, and in the unjacketed of something like 15. In his own trial, quoted above, the ratio of expansion was only a little over 8, which would give some idea of the relative sizes of the engine. In his own case, too, the power developed, 37·66 indicated HP., was much smaller than in the case of the Author's best trials, 72·1 indicated HP.

Mr. Thornycroft. Mr. J. I. Thornycroft said he would confine his remarks particularly to the subject of the engine being divided. His name had been mentioned in connection with this. He did not take much credit to himself, because the idea had cost him little trouble; but he thought it was an important thing in the engine, and he must say, though not in defence of it, that the engine being divided had not been sufficiently appreciated. It appeared to him that for the purpose of the engine under discussion it was a most suitable arrangement. Had the engine been constructed as some speakers recommended, it would have been made with a certain ratio of cylinders which could not be altered, and when it had been once tried and its performance ascertained, with the point of cut-off properly adjusted in the several cylinders, there would be little more to learn from the engine. But a compound engine, where the different parts could be run at different speeds, was one in which, if the engine were quite tight and perfect, the ratio of the cylinders could be altered, as far as possible; in fact, within almost inconceivable limits. He considered that in dividing the engine a great field for inquiry had been opened, because it could be made to represent any particular ratio of cylinders which it was desired to examine. Although the brake had been criticised, he thought it was an object of great interest. The Author had taken Mr. Froude's brake; but finding a defect

Mr. Thornycroft. in it, which at the time was not quite understood, he had turned that defect into a very important and valuable feature. The vortex in that brake was liable to become hollow, and by allowing the water to run out he could regulate the power of the brake within quite sufficient limits for all that was required. When the Author asserted that the engine could be run at from any speed down to 20 revolutions per minute with the load on the brake unchanged, so as to be independent of the speed of the engine, he thought it showed a great success, and the ability to make experiments with three independent engines running at the same time must be, to a certain extent, attributable to the success with which he encountered that difficult problem, and made a brake which would answer his purpose. The trials under discussion included not only a trial of the engine, but a trial of the boiler, made simultaneously. If he differed at all with the Author it was in this, that the work was not all profitable. If the engine was taken alone, and the boiler was made large enough to supply an excess of steam, so that the pressure could be maintained at an exact and constant amount, it would be better than being always hampered with a boiler trial. He seemed to have done it with considerable success, for the results of the different trials were within 1 per cent. The great utility of the engine being divided was shown in the diagrams where the jacketed and unjacketed engines were compared. It was shown that if the engine was jacketed, to get the best results there must be a different ratio of cylinders. Mr. Bodmer had put forward a diagram (*Figs.* 3) showing that in the unjacketed engine he used a different ratio of cylinders, and that the jacketed engine was credited with more economy than it would be if it had a smaller ratio of cylinders. That argument might be turned the other way. It meant that had an unjacketed engine been obliged to run with as large a cylinder as a jacketed engine, the work in the unjacketed engine would have been worse than the Author had shown. He had examined the Author's Tables with great interest, and was certainly astonished to find that with practically the same load on the brakes he was able to alter all the conditions of running, the engines being adjusted so as to give good results in the distribution. He would ask the Author to be kind enough to give not only the good results, but the bad results he might get by using an improper ratio of cylinders for the particular cut-off, because it was not true that a number of useful experiments could be tried with a given ratio of cylinders by varying the cut-off. If the cut-off in the engines was varied, and it was then tried to put a quart of steam

into a pint of space, or the other way about, it would not fit. He thought the Author had hardly done justice to the arrangement in what he had claimed, but he must thank him for the great pains he had taken to bring the matter to that state of perfection. Mr. Thornycroft.

Mr. W. B. Bryan regretted that the Author had not measured the actual amount of feed-water at the trials, so as to compare it with the water discharged from the engines. In a triple-expansion engine which he was about to describe, and which was built by Richardson and Sons, of Hartlepool, in 1887, he had found the missing quantity of water to which the Author referred to vary approximately from 5 to 10 per cent. In endeavouring to compare the work of a triple-expansion pumping-engine belonging to the East London Water-Works Company with that at the Owens College, a few words of explanation were necessary. In each case he had taken the net HP.; in the Owens College engine the brake HP., in the pumping-engine the work actually done in the pumps. The pumping-engine was of the inverted marine type, and the cylinders were 18 inches, 30½ inches, and 51 inches in diameter, with a 3 feet stroke. The high-pressure cylinder jacket was in circulation with the boiler; the intermediate pressure and low-pressure cylinder jackets discharged their condensed water through steam-traps to waste. The normal speed was 23 to 24 revolutions per minute. The plunger-pumps, three in number, were worked direct off the cross-heads. The cranks were set at 120°, and the crank-shaft was prolonged so as to actuate two 18-inch deep well pumps 190 feet below the surface, through two bell-cranks. There were eight bearings. The engine had a surface-condenser, the circulation water being that raised from the well, passing to the plunger-pumps. It would thus be seen that the engine had five pumps to actuate, besides a large number of working parts causing friction. The main steam-pipe was 75 feet long, and the steam-pressure 130 lbs. per square inch. The conditions, as regarded the amount of friction, were in favour of the Owens College engine. A number of trials had been made during the past two years, and the example given showed only average results. The feed-water, discharge from hot-well and jackets, were all from measurements in tanks, the tanks having been graduated from exact weights of water placed therein. All trials were made during the ordinary working of the engine. The power exerted was much less than the engine was designed for, on account of the water in the well having risen to such a height as to drown the pumps to the extent of 130 feet. All the trials were of eight hours' duration. In the ordinary working of the pumping-engine, Mr. Bryan.

Mr. Bryan. just described, the feed-water and the water required to make up the missing quantity were recorded daily. The pump HP. was taken from the water-pressure resistance in the plunger-pumps and lift in the well-pumps, there being no deduction or

PUMPING-ENGINE.

	Lbs.
Feed-water, per hour	2,225·0
Water discharged from the hot-well, per hour . .	1,937·5
„ „ „ ip. cylinder jacket . . .	77·1
„ „ „ lp. „ „	41·1
Total water discharged, per hour	2,055·7
Difference between feed-water and water discharged per hour	169·3
Water condensed in hp. jacket returned to boiler. .	110·0
Pump HP.	140·0
Water per pump HP. discharged from hot-well per hour	13·84
„ „ passing through engine, including all jacket-water, per hour	15·47
Indicated HP.	160·0
Water per indicated HP. passing through engine, including all jacket-water, per hour	13·53

THE OWENS COLLEGE ENGINE.

Trials with cylinder jackets at boiler-pressure.

—	No. 44.	No. 33.	No. 56.
	Lbs.	Lbs.	Lbs.
Water discharged from hot-well and jacket-water per hour	516·00	793·20	977·40
Brake HP.	26·32	45·32	55·15
Water per brake HP. per hour	19·60	17·50	17·72
„ per indicated HP. per hour . . .	15·53	14·23	13·56

addition for any purpose. He might add that the efficiency of the engine in dividing the pump HP. by the indicated HP. for the whole of the trials worked out to between 87½ and 88 per cent. All these were calculated from diagrams taken from a day's running, the diagrams being recorded every quarter of an hour. He thought those results would show that the Author's engine must take the second place.

Mr. Charles E. Cowper. Mr. CHARLES E. COWPER thought the Author must be congratulated upon his excellent arrangement for making a variety of trials. Those who were engaged frequently on engine trials as a matter of professional business would envy the facilities which he had; but they would not envy him the large number of joints and

Mr. Charles E. Cowper.

chances of leakage. With regard to the combined diagrams, Plate 4, Figs. 14, the members would agree it was very much to be wished that engineers should adopt some standard system of comparison. At the present time some half dozen different ways of combining diagrams were adopted, and it was very difficult to compare the results given in one Paper with those in another. The British Association had adopted a standard system of electrical measurement, and he thought that engineers might have a standard system for combining diagrams. He was much disappointed on reading the Paper to find that known leakages and unexplained losses interfered with the value of the results. The Author had some time ago contributed a Paper on the theory of the indicator,[1] in which he discussed very minutely the errors from inertia and momentum of the piston, and other slight imperfections of the instrument. Mr. Cowper accordingly expected, above all things, to find accuracy in this Paper, but he regretted that this quality appeared to be wanting in some of the results. After the first fifty-five trials it was found that some valve was leaking; he looked to the fifty-sixth trial and hoped it would be better, but found, p. 182, it stated that even in this case steam was leaking into the receiver at the rate of ½ lb. per minute, which was rather serious on a total consumption of 12 lbs. Such a result might afford a very excellent text for a professor to lecture his students upon, but he thought that experiments in which leaks had not taken such an important part would have been more valuable as well as more suitable to place before that Institution. The Author spoke of the completeness of the system for checking results. Now what did he find in the Paper? In No. 41 he found the radiation was 421 units; the Author said that was 500 units too small. There was an "error of observation somewhere." He thought it would have been better had the Author thrown aside the results of that trial. But there was a more serious objection, to which other speakers had alluded, namely, measuring the quantity from the hot-well, and not from the feed in the usual way. The Author stated that the feed was carefully measured, with the result that it was from 5 to 10 per cent. greater than the discharge from the hot-well. That 5 to 10 per cent. unexplained loss seriously interfered with the results, and why the Author should charge that on the boiler he did not know. He thought that the boiler, tested before and after the trials, was more likely to be tight than the engine, which had twelve valves, nine piston and valve-rod stuffing boxes, seventy

[1] Minutes of Proceedings Inst. C.E., vol. lxxxiii. p. 1.

Mr. Charles E. Cowper.

flanges and unions, and one hundred elbows, tees, &c.; altogether there were probably two or three hundred joints where leakage might occur. He would ask the Author whether he made independent boiler trials, and whether, in that case, he measured the water in the same way as in the engine trials, or whether he measured it from the feed-water, and omitted altogether the 5 or 10 per cent? Mr. Cowper had found by experiment that still water at the temperature of the hot-well would evaporate at the rate of 1 lb. per hour for each 5 square feet of surface. Of course, when there were waves, the evaporation would be more, and in the present case there were two or three tanks, but he did not know what the surface amounted to. It had already been mentioned that the hot air would come out saturated with moisture from the air-pump, and would so carry away some of the water, as well as some of the heat. With regard to the difference in temperature between the hot-well and the feed-tank, he found that the Author had given it as in some cases zero, and in some between 20° and 30°, and he could only imagine that there was here again some error of observation. Mr. Cowper had selected from the Tables in the Paper some of the most important figures (from a pure science point of view), and had drawn up a balance-sheet,

BALANCE-SHEET—TRIAL No. 56.

Dr.						*Cr.*	
Line.	——	T. U.	Per cent.	Line.	——	T. U.	Per cent.
(44)	Steam in cylinders	14,154	81	(34)	Indicated work .	3,085	17·7
(47)	Jackets . . .	3,325	19	(33)	Rejected in condenser . . .	12,862	73·6
				(41)	Radiation. . .	1,176	6·7
				(40)	Loss from hot-well	356	2·0
(48)		17,479	100·0	(42)		17,479	100·0

placing on the debtor side all the heat in thermal units supplied to the engine, and showing on the creditor side the disposal of that heat, and had calculated the percentage in each case. He might say that he had taken those figures from Table I "without prejudice," that was to say, under protest, because he objected to the first basis of measurement from the hot-well. The result was 17·7 per cent. of indicated work, which was to be discounted by the 5 or 10 per cent. for error, which made 17 per cent.

or 16. It was still a very good result. He might mention that some large pumping-engines by Messrs. Simpson and Co., which were compound, not triple-expansion, gave a little over 15 per cent. indicated work. He ventured to suggest that the adoption of a balance-sheet, in papers of that nature, would effect some saving of time on the part of members who perhaps would not care to read through three or four pages of tables, in the same way as a balance-sheet saved the time of those who would not read through three or four pages of accounts. Mr. Charles E Cowper.

Professor OSBORNE REYNOLDS, in reply, said he should like in the first place to make an acknowledgment of a fact of which he had only become aware within the last two days. He had given the history of the brakes as far as it was within his knowledge. The first brake he made was one from a drawing of the late Mr. William Froude. In the copy of the Paper published by Mr. Froude, there was nothing about any arrangement for admitting water to the centre of the brakes through the veins. He had to thank Mr. J. H. F. Froude for informing him within the last few days that, although his father did not make any statement in his Paper of the necessity, in order to make his brakes work regularly, he had pointed out this necessity of supplying them through the central veins, in the discussion that followed his Paper, and had subsequently employed this method of supplying the water. At the same time, his father had considered the question, which had been suggested in the discussion, of regulating the power of the brakes by regulating the supply of water in them, and had come to the conclusion not to recommend it. These facts were entirely unknown to him when he wrote the history of the brakes, and he was glad to have the opportunity of acknowledging it before the Institution. Coming back to the immediate discussion, he would first beg leave to repeat what was stated in the Paper, and yet more fully stated in the abstract, and again in the few words he said after the Paper was read, namely, that the purpose of the investigation was to determine the exact manner in which the separate parts or organs of the steam-engine performed their several functions. With this view each principal organ had been designed so that it might perform its own special function as perfectly as possible, and at the same time allow of its performance being measured irrespective of the action of the other organs. This necessitated the serious hampering of the engines, taken as a whole, in any economic competitions; but this had been done without the smallest hesitation, any such competition being entirely outside the purpose for which they were intended. So, in making the trials, and re- Professor Reynolds.

Professor Reynolds. ducing the results, every effort had been made to obtain and express the results of each organ separately. He felt it necessary to re-state this, because, by the greater part of those who had taken part in the discussion, this purpose had been either discredited or ignored. Professor Unwin, however, not only acknowledged the purpose, and expressed his approval of it generally, but paid him the great compliment of saying that in several of the more important particulars he had been working in the same direction. It was particularly gratifying to hear him say that he had been working on the same lines in reducing the diagrams. It was the purpose of a reduced diagram to show in detail how far the primary organs of the engine, pistons, cylinders and valves, &c., had performed their part in rendering effective such steam-pressure as was possible under the conditions of working, and further, to separate as much as possible the sources of inefficiency in these organs. Until some such system as that adopted in this research became general, engine-trials would fail to serve what should be their most important purpose, that of showing the immediate sources of inefficiency. These diagrams did not seem to have been well understood by some of those who took part in the discussion, particularly by Mr. Willans, who attributed to a late cut-off what was really due to the setting back of the diagram, so that the ideal compression-line came to the point of zero volume, and appeared to think that such was the shape of the actual diagrams. How far this was the case would be seen by the fac-simile diagrams appended to his reply. He was surprised that Mr. Willans, who had made investigations with the special object of determining the amount of cylinder-condensation, should have had nothing to say about these diagrams, and the manner in which they represented, for every part of the stroke, what Mr. Willans had only given at one or two points. As an illustration of the importance of such diagrams, in which the actual diagrams were set back by the ideal compression-curve, and then compared with the saturated curve, he might point out that had Mr. Willans adopted this plan in his search for the missing quantity, he could not have fallen into the mistake which he had made in estimating the steam accounted for in the cylinder. By taking the apparent steam in the cylinder, less that in the clearance at the point of admission, as the steam accounted for, instead of the apparent steam, less that in the cylinder and clearance at the point of compression, he had taken all the steam condensed during compression as accounted for, and thereby consistently under-estimated the missing quantity, which was the main object of his search. In the high-pressure cylinders,

Professor Reynolds.

where the compression reached nearly to the pressure of admission, the condensation during compression would be very considerable compared with the quantity which had been found missing at cut-off. Again, had Mr. Willans used the mean diagram to show the missing quantity, instead of trying to determine it for one point, and that the point of cut-off, it would have appeared that, in the cases of the higher speed, at this point the missing quantity was apparently less on account of the inertia of the indicator-piston. He hoped Mr. Willans would now be induced to make another reduction of his indicator-diagrams by means of the mean diagram, after the method described on p. 179. In this case he had no doubt Mr. Willans would find the missing quantity at cut-off in his high-pressure cylinder increased some 6 or 7 per cent. at the higher speeds, and that the cylinder-condensation varied with the square roots of the speed. The trials of Mr. Willans appeared to have been so carefully made, and the engines themselves so admirably adapted to test the effect of speed on cylinder-condensation, that it would be a great pity if the results, instead of furthering knowledge, were allowed to remain a stumbling-block for want of accurate reduction. Amongst others, Mr. Willans had asked how he explained the small effect of the jacket on the condensation in the high-pressure engine. In spite of the fact that Mr. Willans stated that he had carefully read the Paper, he must refer him to pp. 184 and 185, where he had carefully discussed this point, and given an explanation. The importance of this explanation was acknowledged by Professor Unwin, who, however, pointed out what he thought was an error in the calculations as to the gradient of temperature necessary to allow the heat to pass through the thickness of the liner in not taking account of the periodic character of the absorption in the cylinder. This, however, was not so, as Professor Unwin would readily see, for the periodic effect extended to such a small distance into the liner, that it had no more effect on the gradient of temperature in the thickness of the liner, than the diurnal demand for water on a service-reservoir had upon the gradient of mean flow from the storage-reservoir. Mr. Bodmer also discussed this point, commencing by questioning the necessity for a flow of heat, and ending, after correspondence, by recognizing such necessity. The examination of this flow of heat through the walls of the cylinder, and the consequent influences on the efficiency of the steam-jackets of the thickness of the walls, and the state of steam as to excess of temperature and purity from admixture with air, was itself one of the objects he had primarily in view during the design and construction of the engine, and

Professor Reynolds. afforded a fair illustration of the character of the others. The accomplishment of this object, so far as the clear demonstration of the importance and character of these influences, was a result which, even if the research were carried no further, would constitute a sufficient scientific reward for the very considerable undertaking in instituting and working these engines. He hoped, however, to go further, both in extending the knowledge of these influences, and in clearing up other doubtful questions. The excess of heat in the discharged steam over that it possessed at release, was another important matter that had been examined and established in these trials. This point, however, had not been entered upon in the discussion. Mr. Beaumont's comments were merely an attempt to show that a discrepancy between the measured and theoretical heat discharged in one of the trials was owing to an error in estimating the heat theoretically discharged in all the trials without jackets. Mr. Beaumont overlooked the fact that by altering the formula to suit the one anomaly, he would bring an equal anomaly into both the others. In his formula Mr. Beaumont put a wrong construction on the total heat of evaporation, overlooking the fact that this included the external work done during evaporation against the pressure of the surrounding steam. Coming to the criticisms on the engines, and method of conducting the trials, he would first thank Mr. Thornycroft for his appreciatory remarks generally, and particularly for so clearly pointing out the advantage to be derived from the separate brakes, which remarks relieved him from the necessity of replying to such criticisms as had been made by other speakers except to acknowledge Professor Unwin's appreciation of these advantages. Respecting the indicating-gear, he acknowledged with pleasure Professor Unwin's kindness in showing him his laboratory, and although he had no recollection of the indicating gear doubtless saw it, as he remembered being struck by the single indicator with alternative pipes. He willingly admitted that if there were any points of resemblance in the two gears that were not common in other gears, he might unconsciously have adopted them. In respect, however, to the specialities in the gear he had described, and which alone seemed to make it worth describing, they, as far as he could see from *Fig. 2*, were entirely absent from Professor Unwin's gear. He had not—(*a*) the stiff steel wire, held straight and tight by a spiral spring, in such a position that both indicators could take motion from it with equal, and the shortest possible, lengths of cord; (*b*) the buttons on the wire, and the claw-hooks, which constituted the principal feature of the gear, allowing of hooking up at any speed with equal facility, and

Professor Reynolds.

this without adding sensibly to the weight of the moving parts; (c) the simple method of attaching the gear to the indicator-cocks without other fixing. These features rendered the gear the simplest gear to work with two indicators that he knew, and specially adapted it for high speed, it being as easy to work at 600 revolutions per minute as at 100. It was no object of his to disparage Professor Unwin's gear, which seemed excellent as regarded facility for a single indicator at low speeds. It did not, however, seem well adapted for two indicators, and if run at a high speed the weight of the spring and double pulleys, in the middle of a long cord, would seriously disturb the motion of the drum; while if wire were used, it would frequently break from bending, or if thin from overloading. The defect in the rider-valve mentioned, p. 183, in connection with the discussion of any possible leakage that might explain the missing steam shown in the diagrams, was only revealed by a most rigorous examination of the diagrams, and its effect on the distribution of steam and the efficiency of the diagrams was insensible, being only a slight wire-drawing for a little way from the cut-off. The leak through the steam-valve into the receiver No. II, in trial 56, was an incident of the trial, and only discovered in virtue of the exceptional facilities offered in these engines for observing the condition of each part separately. That these two slight defects should have been the only defects found in the six trials, notwithstanding the closeness of the watch kept on every part, was the very strongest assurance of not only the good, but the very high condition of the engines. Where no defects had been recorded, it might be that things had been perfect, but it was infinitely more probable that defects had not been looked for. In careful scientific work, it was a rule to record the largest errors, as affording definite information as to the degree of accuracy. This rule he had followed. As to discarding any trial on account of these defects, which were revealed after or during the trials, this would seem very much like picking out favourable trials, to prevent which it was made a rule in this investigation to record every trial with its defects. The loss of steam or water was a defect common to all steam-engines and boilers, though the extent of this loss was seldom known, even approximately. Indeed, it was only in the case of surface-condensing engines that it could be measured at all, and then the apparent loss was liable to be less than the actual loss on account of water leaking back into the condenser. It was almost impossible to determine the leakage of a surface condenser working under ordinary conditions. Like a boiler it might be

Professor Reynolds. tested cold and found tight, yet leak badly when hot. The Owens College engines afforded exceptional opportunities for testing the condenser. No water but what passed through the engines was admitted to the condenser; while, not only was this water always measured, but also the heat given up by this water; and hence the heat showed how far the water entered as steam or leaked in as water. This check might not be within 3 or 4 per cent. of the water passing through the engines, so that with 20 lbs. a minute it would still be possible to overlook something like $\frac{1}{2}$ lb. per minute. It was, however, possible to keep the condenser under the same conditions as regarded pressure and temperature when passing 1 lb. per minute as when passing 20 lbs., and then the heat checked the water to $\frac{1}{20}$ lb. per minute. Several trials of this kind had been made, and had shown no determinable leak whatever. In this way the actual difference in the feed and the discharge from the hot-well was shown to represent, not only lost water, but all the water lost. As regarded the question how far 5 or 10 per cent. was a usual loss of water, it might be noticed that the statement of loss given in the Paper referred only to triple-expansion trials with 200 lbs. steam-pressure, conditions on the extreme limit of practice, so that there was every probability that the loss of water in these engines would be beyond the ordinary. He had heard from many engineers experienced in working marine engines that 5 per cent. was the minimum loss at high-pressure. Mr. Bryan stated that he had found the lost water from 5 to 10 per cent., and gave an instance in which the loss was 7·7 per cent. with about 130 lbs. of steam. At the time of writing the Paper the loss occurring at lower pressures had not been determined; it had since been done, and it was found that up to a pressure of 90 lbs. the loss did not exceed 10 lbs. an hour, and hence the loss of from 40 to 50 lbs. an hour, which occurred at about 200 lbs. pressure, was to be attributed to the pressure. In the matter of liability to leakage from the engines and boiler, these engines were under much the same conditions as marine engines; but in respect of the water-heater and of the complicated system of pipes for supplying the jackets and under full pressure of steam, they were at a great disadvantage. On the other hand, very exceptional efforts had been made to render these engines tight. Every leak was stopped as soon as it was seen, and the boiler, economizer and the entire jacket system were tested under cold-water pressure. On the last occasion when this was done, pressure was kept up at 200 lbs. per square inch for two hours with 20 lbs. of water. Nevertheless, during the engine-

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trial on the next day, 200 lbs. of water were lost in four hours. That the bulk of the lost water escaped as steam or water, through apertures in the envelope subject to high pressure and high temperature, seemed certain; but where these apertures were, whether numerous minute leaks or one larger leak, had not been ascertained. That no sensible quantity of water left the jacket-pipes was certain, these pipes being all well above the floor. If the pipes, therefore, leaked water, this water was evaporated by the heat of the pipes, the heat being replaced by the condensation of steam in the pipes, &c.; in this case, the quantity of water which returned from the jackets was not affected. The water that escaped from the glands of the high-pressure and the intermediate engines had been definitely shown to be very small. The glands had always been worked tight, namely, screwed up on the least suspicion of a leak. In some of the trials special precautions had been taken. In the trial already mentioned as following the cold-water test the glands were treated as usual, but the packing was rather old, so that when the 200 lbs. of water were lost, to be certain of the glands they were repacked, and another trial was made with the glands screwed and the rods kept cool by continuous tallowing. The glands were several times tested with cold polished steel, and no dew was found. The loss of water was 218 lbs. in the four hours. It had been suggested that the lost water had been discharged as vapour from the air-pump, or had been evaporated from the tank. If this were so there would be the same loss in low-pressure trials as in high, for the condenser and tanks were under the same conditions. The only tank exposed was the feed-tank and the tip-can, in which the temperature of the water was within 2° of that in the hot-well. While considering that the feed-water could not contain more than one-hundredth of its volume of air at atmospheric pressure, the air discharged from the air-pump must be so small that it could not carry away any sensible moisture. He had, however, made arrangements to measure the air and vapour from the air-pump; these arrangements were not quite complete, but they enabled him to say that the volume of air and vapour did not appreciably exceed that of the one-twentieth part of the water discharged. He had replied at length to the remarks on this loss of water, because, for one reason, it seemed to have been the opinion that it had been rather slurred over. He hoped what he had now said would be sufficient to show that, so far from such being the case, it had been pursued by every means at his disposal. Considering that such a loss of water was a matter of general occurrence with high pressures and

Professor Reynolds. surface-condensers, he considered its investigation to be of very great interest and importance. If the water was lost as steam, such a loss, if a necessary accompaniment of high pressures, must largely diminish the economical advantage, which would otherwise be realized. While the revelation, by the measurement of the feed- and hot-well discharge, of a loss of more than 5 per cent. of the feed-water, which so far defied, not only all usual means of detection, but every means that he had been able to apply, must, until it was cleared up, cause grave doubts in accepting any conclusions as to the behaviour of steam in the engine, based upon trials in which the feed alone had been taken as showing the quantity of steam passing through the engines.

The severe criticisms of Mr. Willans seemed to demand some notice, which, however, had been made difficult by the attitude which he had taken. He began by disputing the Author's motives for these trials, and stated that "the Author wished to beat the record," and perverted a passage in the Abstract, in which any such motive was disclaimed, into a claim to have beaten the record. The manner in which these engines had been hampered with excessive radiating-surface and shafting, should have shown that general economy had been a secondary consideration. But this did not suit Mr. Willans; he was determined to compare these trials with his own, and so placed Professor Reynolds in the position of a competitor, in order that he might ignore the otherwise very obvious reason for the methods of reduction which had been adopted, and imply that they had only been adopted to place the economic results in a favourable view. This seemed neither courteous nor fair, and he must entirely decline to take the position of a competitor for economic precedence, although, were economy any object, it would be somewhat flattering to find Mr. Willans, who clearly considered himself the champion of the record, so anxious for his position. It was perfectly open to make any economic comparison so long as the results were dealt with accurately, and no misleading impression of them was conveyed. To begin with, Mr. Willans re-stated the Author's results, discounting the economic advantage (about 5 per cent.) which was obtained by means of the water-separator returning the water condensed in the jackets to the boiler, measuring it on its way, which arrangement Mr. Willans in another place described as admirable. Not content with this, he attacked the method of estimating the jacket-water by measuring it accurately over an interval of five minutes every half-hour, because "only one-fifth of the jacket-water had

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in this trial gone through even a form of measurement." "A form of measurement!" The water was collected in a carefully calibrated vessel, under full pressure of steam; while in place of this Mr. Willans proposed to take it out into the open air and weigh it, regardless of the fact that one-fifth part of the water would immediately pass off as steam. The measurement of jacket-water had always been a difficulty, and those having experience of this would, he felt sure, appreciate the advantage of this separator. There was no necessity to limit the intervals of measurement to five out of every thirty minutes; it had sometimes been measured for twenty-five out of the thirty minutes, yielding similar results for similar trials. In some trials, all the water had been drawn off from the blow-off cock, keeping the water in the gauge at a certain level, so as not to allow steam to pass, the water being caught in buckets and weighed, a weighed quantity of cold water having first been put in the buckets to condense the steam. This was an accurate, though laborious method, which could not be used without the water-gauge. In this way both the gauge and the method had been severely checked. If the working of engines was so regular that indications for a period of less than half a second every half hour were deemed sufficient, surely the definite measurement of the jacket-water for periods of five minutes every half hour might pass without question. Mr. Willans attempted to discredit the usual method of reducing diagrams by means of ten breadths. After asserting that "the measurement could only be accurately done by means of a planimeter," Mr. Willans proceeded to say that if the area of the low-pressure diagrams (Plate 4, Fig. 14, trial 33), were taken by ten breadths, it would be at least 5 per cent. greater than if taken by the planimeter. It was difficult to believe that this was merely a guess; yet, if Mr. Willans had actually compared the measurements, he must have effected observation errors of at least 3·8 per cent. The figure was a sufficiently definite one, and as the essential error of the method of ten breadths depended solely on the figure, and not on the scale, and the area of a similar figure on a sufficiently large scale could be definitely and accurately measured, say to 0·02 per cent., and also by ten breadths to the same degree of accuracy, the error of the method of ten breadths, as applied to this figure, admitted of definite determination. Having in his possession the original mean diagram, of which the scales were 10 lbs. to an inch and 2 cubic feet to an inch, from which the diagram in question was a copy, reduced first by the pentagraph and then by the engraver, he had the large diagram measured, so as to obtain its mean breadths to less than

Professor Reynolds. one-thousandth part, as well as by the method of ten breadths.[1] He thus found that the excess by the method of ten breadths was 1·2 per cent. It might seem that these were very small errors to dispute about, but they were very important. If the ten-breadths method gave ordinary diagrams 5 or even 3 per cent. too large, it would be unfit for use, and all the results hitherto obtained by its aid would be subject to this error. Its standing error was, however, nothing approaching 5 per cent., not even 1 per cent. The diagram selected by Mr. Willans was not an indicator diagram, and had a figure which entailed a much larger error by the ten breadths than actual diagrams, such, for instance, as those in the Appendix to this reply, would entail. The planimeter was an extremely useful instrument, but still it had errors of its own, particularly when used in certain positions, positions in which it was very apt to be used. But these standing errors were not the only ones in measuring diagrams; the errors of operation, which increased as the size of the diagrams diminished, were apt to take a particular direction. To make a free-hand tracing with a vertical pencil of a diagram, not more than ½ inch broad, and with a line something like 0·01 inch thick, and to maintain the true area to at least 2 per cent., required conditions of light and an

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[1] To measure the diagram, its length was divided into 20 equal parts, and the breadth at each of the points of division was measured, also the breadths at the ends. These measurements commencing, from the left end, which point was indicated as zero, were given in order under the figures 0, 1, 2, 3, &c.

0	1	2	3	4	5	6	7	8	9	10
0·15,	1·44,	2·05,	2·00,	2·03,	2·05,	2·03,	1·95,	1·70,	1·44,	1·25,

11	12	13	14	15	16	17	18	19	20
1·02,	0·92,	0·82,	0·76,	0·70,	0·63,	0·565,	0·51,	0·475,	0·18.

Mean breadths were thus obtained—

(1) Mean of the alternate ten breadths . . . . . . = 1·2460
(2) „ half-end breadths and remaining breadths, Trapezoidal rule . . . . } = 1·2045
(3) Mean by Simpson's rule . . . . = 1·2321

If (1) was too large (2) was too small, and the probable true mean was given according to Simpson's rule, by adding twice the first to the second and dividing by three. To check the accuracy of this estimation, as the end trapezoids were the only ones in which there was irregularity, the mean breadths of these were measured by the planimeter. These were for the first 1·326, and for the last 0·430. These added to the sum of the breadths from 2 to 18, taken out by Simpson's rule gave the mean breadth = 1·2312, which checked the other to 0·08 per cent.; then subtracting these from (1) the excess of the method of ten breadths = 0·0148 and 0·0139, or 1·2 per cent.

Professor Reynolds.

amount of skill extremely difficult to attain, while the ten breadths could, by the aid of an engraver's glass, be measured to almost any degree of accuracy. Another respect, in which Mr. Willans' statements were calculated to cast discredit on the method of reducing the results of these trials, was that of the thermal and the theoretical efficiencies. In the Paper, thermal efficiency had been used in a somewhat restricted sense, compared with the somewhat loose manner in which it was often used. Its application was restricted to the special organs in which the steam operated to perform work; thus it was used to express the ratio which the heat converted into work bore to the heat received into the engine proper, instead of confusing this heat with that lost by radiation, or otherwise lost. This restriction was defined in the Paper and in Table II, "Thermal efficiency as given by heat discharged in condensing water." The purpose of so restricting it was obvious, namely, to keep the results depending on the action of these organs separate from other and quite independent organs. Mr. Willans objected to this step towards localizing the imperfections of the engine, apparently because it had not been previously taken. He insisted on again mixing up the radiation with the internal action of the engines, as if it were wrong to separate them. This, however, was not so much the point. The restricted thermal efficiency depended on two distinct actions, one the action of the steam under the conditions aimed at in the engines, the other the action of the engine in fulfilling these conditions. Thus the thermal efficiency was the product of two efficiencies, one called by Rankine the efficiency of the steam, and commonly "theoretical efficiency," the other as yet without a name, but determined by the ratio which the thermal efficiency bore to the efficiency of the steam, and expressed as "percentage of theoretical efficiency." It was, if strictly determined, the most important quantity of all the results of the trials, as it expressed the efficiency of the primary organs of the engine in performing their functions, while, if incorrectly determined, it was simply a source of confusion. This might be called the physical efficiency of the engine. To obtain correctly this physical efficiency, it was necessary to find the thermal efficiency, free from all confusion by extraneous circumstance, and also the efficiency of the steam according to the conditions under which it was used. In these trials with jackets the conditions aimed at were clear. Every effort had been made to keep the steam saturated while expanding from the pressure of admission to that at which it was released, to be discharged from the cylinder against the pressure

Professor Reynolds. of the condenser, the release-pressure being controlled by the load put upon the engine. Now, the efficiency of dry saturated steam under such conditions had been known for more than thirty years, and there were no two opinions about it. Rankine and Clausius has given formulas which led to the same results. These theoretical efficiencies of the steam (Table III, p. 194), had been obtained directly by interpolation in Rankine's tables, according to Rankine's formula, given in Article 287 of his "Manual of the Steam-engine and other Prime Movers."

$$\text{Efficiency } \frac{U^1}{h} = \frac{U_1 - U_2 + v_2 (P_2 - P_3)}{U_1 - U_2 + H_2 - h_4}.$$

Mr. Willans, entirely ignoring the scientific importance of these terms, and observing only that, by taking the efficiency of steam under conditions which were not those aimed at in the trials, he could lower the percentage of theoretical efficiency, objected to the Author taking the correct efficiency for steam, and constructed a table in which he placed the theoretical efficiencies for the six trials as given in the Paper, and above these, three rows of theoretical efficiencies, all decidedly higher than the Author's, and differing from each other in an ascending scale, as if to prove, by mere weight of evidence, that the efficiencies given in Table III were too low.

The first two of these rows of efficiencies, "the theoretical efficiency of Carnot's cycle," and "the theoretical efficiency of Clausius' perfect engine," were clearly inapplicable to the trials in which the conditions did not approximate to Carnot's cycle any more than they did to those of Clausius' perfect engine. The third row of efficiencies was headed: Theoretical Efficiency of Jacketed Engines: Heat utilized per lb. of steam $= 1{,}438 \log_e \frac{A}{B} - 0{\cdot}7$ $(A - B)$. Standing thus directly over the results which the Author had given, obtained from Rankine's formula, there could have been but one intention, namely, to convey the idea that the Author had misused Rankine's formula and underestimated these theoretical efficiencies. What then was the fact? Mr. Willans had given a formula, emphatically not Rankine's, had headed the results calculated by this formula "Percentage of Theoretical Efficiency of Rankine's Jacketed Engine," and placed them immediately over the "Author's percentage of theoretical efficiency" (lines W and X). Rankine had given no rule for the theoretical efficiency of a jacketed engine, but he gave a formula for the

efficiency of dry saturated steam, which was the same as was now commonly meant by the theoretical efficiency of the jacketed engine. He also had given a formula for the heat utilized per lb. of dry saturated steam, which was— Professor Reynolds.

$$U' = a \log_e \frac{\tau_1}{\tau_2} - b(\tau_1 - \tau_2) + v(p_2 - p_3),$$

in which the suffix $_1$ referred to admission, $_2$ to release, and $_3$ to the condenser. It was this formula that Mr. Willans had used in concocting his own; he had put A for T_1, B for T_2, and left out the important final term. Nor was this all: in calculating the results Mr. Willans had, for B or T_a, the temperature of release, substituted the temperature of the condenser, which in these trials was some 60° Fahrenheit less than the temperature of release. The Author forbore all comment on this proceeding on the part of Mr. Willans, merely quoting some of Mr. Willans' statements as to his own methods of proceeding and those of the Author. "He," Mr. Willans, "had therefore, from the Author's data named above, re-calculated all his figures as to efficiency in the standard methods." "He (the Author) compared what he called 'thermal efficiency' with something which did not, to Mr. Willans, represent the 'thermal efficiency' of any engine or cycle whatever." "Looking at the matter broadly, it seemed to Mr. Willans that the Author had increased the efficiencies in the various trials by omitting factors always of great importance, and in this case of a special importance, and that he had then compared these inflated results with a new standard for which there was no sound reason."

Having now replied to all the more important criticisms, he would only say that he had offered the results to the Institution, believing them to be of interest and importance; that he regretted his inability to render the Paper more easily intelligible, and that he had every confidence its importance would be more and more realized as it became better understood. And in thanking the meeting for the kind attention paid to the Paper, he would express the hope that some good would be found to come out of it.

Professor Reynolds.

TABLE.

Number of the trial	44	33	56	41	35	40
Lbs. of coal put upon the fire during the trials, including 14 lbs. of wood taken as 7 lbs. of coal	321	487	411	365	521	509
Lbs. of coal deducted for fuel left unconsumed at the end of the trials	21	21	21	21	21	21
Lbs. of coal consumed during the trials	300	466	390	344	500	488
Lbs. of water discharged from the hot-well supplied to the boiler at the temperature of the feed during the trials	2,095	3,595	3,000	2,790	4,266	4,308
Lbs. of water added at the temperature of the feed to make up the feed during the trials	..	288	..	..	278	273
Lbs. of jacket- and priming-water returned from the water separator by gravitation to the boiler at the temperature of the boiler during the trials, being the product of the rate per minute given in Table I, line 46, and the duration of the trial in minutes	944	1,365	960	595	725	646
Lbs. of total water supplied to the boiler during the trials, including water lost	..	5,248	..	..	5,269	5,227
Lbs. of water supplied to the boiler during the trials, excluding water lost	3,039	4,960	3,960	3,385	4,991	4,954

WHITWORTH ENGINEERING LABORATORY, THE OWENS COLLEGE, MANCHESTER. Professor Reynolds.

December 4, 1888. Name, C. S. THOMSON. Engine No. II.
Indicator D. Spring 60.

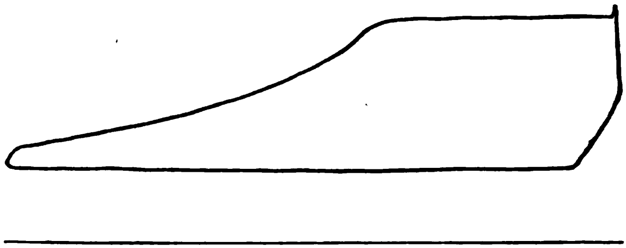
No. of Diagram.	Time.	Boiler Pressure.	Receiver Pressure.		Greatest Indicated Pressure.	Least Indicated Pressure.	Release Pressure.	Mean Effective Indicated Pressure.	Revolutions per Minute.
			No. –.	No. –.					
	A.M.								
1	10.0	193	59·0	9·0	59·0	9·0	17·0	30·7	250
2	10.30	192	58·0	8·5	58·0	7·5	16·0	29·35	240
3	11.0	180	58·0	7·5	57·0	8·5	16·5	29·0	240
4	11.30	179	56·0	7·5	55·0	7·0	16·0	29·45	222
5	12.0	184	58·0	7·5	57·5	7·0	16·0	30·8	240
	P.M.								
6	12.30	185	61·0	8·0	58·0	7·0	12·0	30·6	230
7	1.0	180	58·0	8·0	58·0	9·0	17·0	28·35	260
8	1.30	190	56·0	8·0	57·0	9·0	17·0	28·8	260
9	2.0	185	60·0	8·0	57·0	5·0	13·0	29·3	248
10	2.30	184	58·0	7·0	56·0	8·0	16·0	28·6	214
11	3.0	185	59·0	7·5	59·0	8·5	17·5	29·7	230
12	3.30	181	58·0	7·0	60·0	7·5	16·0	31·1	200
		2,218	699·0	93·0	691·5	92·5	190·0	355·75	2,834
		185	58·25	7·7	57·6	7·7	15·8	29·64	236

Professor Reynolds.

TRIAL 33.—FULL-SIZED DIAGRAM XII

FRONT END.

Engine No. I.

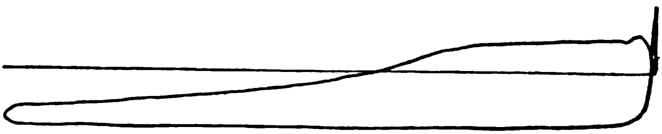


Revolutions 200. Spring 150 lbs.

Engine No. II.

Revolutions 230. Spring 60 lbs.

Engine No. III.



Revolutions 252. Spring 40 lbs.

TAKEN at 3 P.M., DECEMBER 4, 1888.

Professor Reynolds.

BACK END.

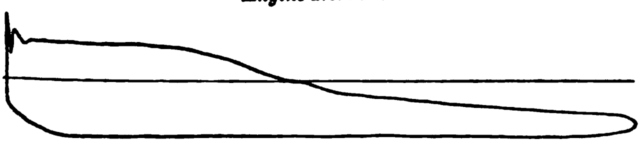
Engine No. I.

Revolutions 200. Spring 150 lbs.

Engine No. II.

Revolutions 230. Spring 60 lbs.

Engine No. III.



Revolutions 252. Spring 40 lbs.

Correspondence.

Professor Dwelshauvers.

Professor V. DWELSHAUVERS DERY observed that in his view the Author's experiments were unexceptionable, and made under conditions which gave them considerable importance. It was so much the more to be regretted that they were insufficiently detailed. In fact, to study them, and to investigate the bearing of the walls of the cylinders after the method of Hirn, it would be necessary to have for each cylinder separately the volume of the dead space, and the volume occupied by the steam at the commencement of each of the phases of admission, expansion, exhaust, and compression; the pressure of the steam at each of these periods; the work of this pressure during each of these phases; the mean diagram for each side of the piston; the external radiation of each cylinder and of each receiver; the quantity of heat transferred by the steam in each jacket. In fact, the data ought to be sufficiently complete to allow of the application of the six equations of the practical theory. With the information supplied in the Tables, only the first equation could be established, the equation of control, the balance-sheet of the trial. Without doubt, some conclusions relative to the facts might be deduced from it; but it was not clearly elucidated either in respect of the reason of, or of the method of the economies realized. He had applied so far as possible his method of investigation to these experiments. It consisted in bringing into account all the quantities of total heat expended, and in expressing them as fractions of this total heat. This was composed of two parts; first, the heat brought to the cylinder by the steam, Q, reckoning from 32° Fahrenheit; secondly, the heat Q′ of the jacket steam, total $Q + Q'$. This heat ought to be found again (1) in the external work accomplished, represented by T thermal units; (2) in the external radiation E; (3) in the heat given up to the condenser composed of two parts, namely, that which had been furnished to the cold water, C, and that which the condensed steam possessed above 32° Fahrenheit, c; and for the sum $(C + c)$.

There then was: $Q + Q' = T + E + (C + c)$,

$$\text{and} \qquad 1 = \frac{T}{Q + Q'} + \frac{E}{Q + Q'} + \frac{(C + c)}{Q + Q'}.$$

In the six trials given there were—

Professor Dwelshauvers.

—	44	33	56	41	35	40
$\frac{Q}{Q+Q'}$	0·749	0·789	0·817	0·870	0·893	0·905
$\frac{Q'}{Q+Q'}$	0·251	0·211	0·183	0·130	0·107	0·095
$\frac{T}{Q+Q'}$	0·152	0·164	0·170	0·124	0·135	0·136
$\frac{E}{Q+Q'}$	0 132	0·096	0·065	0·047	0·058	0·050
$\frac{(C+c)}{Q+Q'}$	0·716	0·741	0·764	0·828	0·807	0·814
$\frac{Q'-E}{Q+Q'}$	0·119	0·115	0·119	0·083	0·048	0·045

By this process, it would be seen clearly that No. 56 gave the highest efficiency; that for some unexplained reason the external radiation E was in that case very feeble; that the heat Q′ − E supplied to the steam in the first three trials was very nearly the same. The reason then of a greater efficiency in trial 56 was not apparent; but it was, however, a question which deserved to be cleared up. The Paper contained sufficient data to determine the thermal efficiency, f_1, that of the fluid, f_2, that of the mechanism, f_3, and consequently the ultimate efficiency $f_1\ f_2\ f_3 = f$. By thermal efficiency he meant the fraction $\frac{\tau - \tau^1}{\tau}$ in which τ was the absolute temperature of the source of heat (of the steam in the boiler), and τ^1 was the absolute temperature of the cold condensation water, of the cold body. The temperature of the cold water varied greatly from one trial to another, insomuch that the possible fall and the thermal efficiency varied for the highest and the lowest as much as 5·5 per cent. from the mean. He called f_2, fluid efficiency, the relation between the work indicated and that which should be obtained from a Carnot ideal motor with the same expenditure of heat and the same fall of temperature. Lastly, f_3 was the relation between the brake HP. and the indicated HP. From the highest to the lowest the difference varied about 5 per cent. from the mean of this efficiency, but the reason for this variation was not very apparent. In each of the two series, with and without steam in the jackets, the efficiency of the mechanism was greatest at mean speed. With steam in the jacket it was least for the highest speed, and without steam for the lowest speed. If, therefore, it

Professor Dwelshauvers. were desired to determine either the benefit due to the jacket, or that due to the influence of the speed, it would be necessary to disregard f_1 and f, and consider only f_2. At the outset he would consider the efficiencies deduced from the data in the Paper:—

—	1	2	3	4	5	6
	44	33	56	41	35	40
	With Steam in the Jacket.			Without Steam in the Jacket.		
f_1	0·3944	0·3732	0·3904	0·3936	0·3795	0·3918
f_2	0·3864	0·4389	0·4360	0·3290	0·3802	0·3766
f_3	0·7921	0·8128	0·7649	0·7869	0·8266	0·7969
f	0·1207	0·1331	0·1302	0·0978	0·1114	0·1080
$f_1\ f_2$	0·1524	0·1638	0·1702	0·1243	0·1347	0·1356

The last line, the product of $f_1\,f_2$ represented the relation between the heat equivalent to the indicated work and the total heat expended. The economical effect of the jacket was shown by a comparison of the trials, made at approximately the same speed, 1 and 4, 2 and 5, 3 and 6, with respect to the value of f_2 only:—

$$\text{Trials 1 and 4}\quad \frac{3{,}864 - 3{,}158}{3{,}864} = 0\cdot183,$$

$$\text{,, 2 and 5}\quad \frac{4{,}389 - 3{,}549}{4{,}389} = 0\cdot191,$$

$$\text{,, 3 and 6}\quad \frac{4{,}360 - 3{,}455}{4{,}360} = 0\cdot208.$$

The mean advantage was 0·194, or 19·4 per cent., the highest being in respect of the highest speed. To find the advantage resulting from high speeds, he would compare in the same way trials 1 and 2, 2 and 3, 1 and 3 with the jacket, and trials 4 and 5, 5 and 6, 4 and 6 without the jacket. This would give:—

Trials 1 and 2, advantage	0·1196	Trials 4 and 5, advantage	0·1102
,, 2 and 3, ,,	0·0067	,, 5 and 6, ,,	0·0272
,, 1 and 3, ,,	0·1138	,, 4 and 6, ,,	0·0860

The maximum efficiency of the fluid was therefore obtained at mean speed; but the highest speed gave greater efficiency than the lowest. He hoped that the data in the Paper would be ex-

tended, so as to allow of a more thorough analysis of the thermal phenomena observable in the experiments. Professor Dwelshauvers.

Mr. Donkin. Mr. BRYAN DONKIN, Jun., said he would like to know how the radiation experiments had been made. It would much increase the interest of the Paper if the Author could add any experiments giving the result of each set of steam-jackets separately, so as to determine their relative effect; also if he could divide in the same way the returns of the total weights of jacket-water. If an experiment could be made with the three engines coupled in the usual way, as in mill and marine engines, it would be of great value. His new hydraulic brake dynamometer was especially interesting and complete, and was likely to be much used in similar experiments on account of its small size and its easy application. The great difference between the feed-water into the boiler and out of the air-pump was startling; but no doubt the Author would be able to reduce this in future experiments, or determine the reason for the differences. As the balance-sheet system of heat in and heat out had been used in this Paper, as in many other similar trials, and had been so largely adopted of late years by engineers, it might be of interest to state that, after some trouble, Mr. Donkin had succeeded in tracing when and by whom it originated. Professor Dwelshauvers Dery, of Liége, informed him that it was first employed by Mr. Hirn in the following Paper:—"Mémoire sur l'utilité des Enveloppes à Vapeur."[1]

Mr. Kirk. Mr. A. C. KIRK could not refrain from a note of warning, that results got from a model, however carefully and correctly the trials might be carried out, should not by any means be implicitly accepted as applicable to a large engine. As an illustration, the late Mr. Froude's observations on the behaviour of ship models towed in a suitable tank, while they might in any case have been of some interest, would have been of little value had not that illustrious experimenter found a law of comparison between the results from the models and those of the full-sized ship, and been able to prove by experiment that the law held true. It might, perhaps, be said that so far as the action of the walls of the cylinder was concerned, the law of comparison was simply that (under the same conditions of temperature, of expansion, &c.), while the weight of steam used in the cylinder would be as its cubic capacity, the action of the sides of the cylinder would be in proportion to the surface exposed to the working steam. But this should by no means be hastily assumed, and it might possibly be

[1] Bulletin de la Société Industrielle de Mulhouse, vol. xxvii. (1855), p. 105.

Mr. Kirk. a considerable way from representing the truth. Without investigating the hypothetical conditions that might prevent the application of such a law, one obvious condition would probably modify it materially, namely, that the steam acting inside the cylinder was not at rest, expanding quiescently, but was, on the contrary, in a state of violent agitation and movement. Under these conditions how much of the steam came in contact with the sides of the cylinder no one, perhaps, would venture to guess. His feeling was that, while these experiments were of value, the results obtained were only applicable to small engines. On the Paper itself he would make a few remarks. In engines where the steam was worked through a considerable range of expansion in one cylinder, experience had proved beyond doubt that the use of a steam-jacket effected economy, that, in fact, the steam condensed in the jacket produced more power than the same steam would do if admitted to the cylinder as an addition to the working steam. Unfortunately the Author seemed to ignore this essential condition. As formerly practised in single-expansion engines, Mr. Kirk would not venture to assert that the interior of the cylinder was kept absolutely dry by the action of the jacket, as the steam in the jacket did not exceed in temperature the working steam admitted to the cylinder. About eighteen years ago, the idea took strong hold of many engineers, that much higher economy could be attained in the compound engine by keeping the inside of the cylinders dry. Not only was much attention given to steam-jackets in cylinders and covers, and an attempt was even made to keep the pistons hot by steam inside them; but further, to make sure that the working steam was dry before it entered the engine, it was passed through a steam receiver and separator heated by the waste heat of the chimney. There was little doubt that dry steam was in this way obtained, and that the inside of the cylinders was kept dry during the passage of the steam through them; but, in consequence, the cylinders and valves often cut badly, and the enginemen used so much oil inside the engine that harm was done otherwise. It came to be recognized that it was objectionable in practice to work a cylinder without some moisture to act as a lubricator. Thus the Author's condition of working with the low-pressure cylinder, kept so hot as to act as a powerful evaporator, however interesting it might be in some ways, was a matter outside practical engineering. Glancing, now, briefly at the combined indicator diagrams, there seemed to be anomalies needing explanation. The diagrams having been reduced so as to correspond to an engine with all the pistons working on one

crank-shaft, and consuming 1 lb. of steam per stroke, a curve of dry saturated steam was drawn for the sake of comparison. The quantity of steam was deduced from the water discharged from the air-pump, the capacity of the low-pressure cylinder being taken so as to contain 1 lb. of steam at the pressure of release. In the case of the unjacketed cylinder, the steam shown by the diagram was not sufficient to fill this cylinder, and there was a quantity missing, represented by the shaded belt between the actual diagram and the curve of saturation. In the case of the jacketed trials this belt in the low-pressure cylinder, and partly in the intermediate cylinder, had all but vanished. From this it must be inferred that water passed into the engine had been evaporated chiefly in the low-pressure cylinder, and had filled it with dry saturated steam, which then had passed out of the cylinder into the condenser. But, looking at the high-pressure diagram, it did not seem that this amount of dry saturated steam discharged from the engine ever got into the engine. It could hardly be assumed that, with the precautions taken, and the high-pressure cylinder steam-jacketed, all this missing steam was due to condensation of dry saturated steam entering the high-pressure cylinder, amounting as it did to about 50 per cent. of the actual working steam. It would seem rather as if a considerable quantity of water had passed from the boiler, in the first place along with the steam, which on its way through the engine was gradually evaporated by the action of the jackets, and chiefly so in the low-pressure cylinder, where the temperature of the jackets was much above that of the working steam and the water which accompanied it. The use of boiler-steam, at 200 lbs. pressure per square inch, to evaporate water in the low-pressure cylinder and generate steam in it of about 25 lbs., which, after doing some work there, escaped direct to the condenser, could not be economical. It would be better if this steam at boiler-pressure were admitted as working steam to the high-pressure cylinder. There seemed to be a slight mistake in not setting back the low-pressure diagrams in trials 40, 41, and 44 to zero line. When this was done in trial 40 it would be found that the diagrams followed very closely the line of adiabatic expansion, as the diagrams of the trials of the triple-expansion engines of the steamship "Aberdeen" were found to do.[1] Mr. Kirk's view was that, seeing the presence of water in a steam- Mr. Kirk.

[1] For further information on these triple-expansion engine-trials and the method of setting out a continuous diagram, see Mr. Kirk's Paper in the Transactions of the Institution of Naval Architects, vol. xxiii. (1882), p. 33.

Mr. Kirk. cylinder was unavoidable, it was better to divide expansion into successive stages in cylinders of graduated temperatures than to trust to the action of the steam-jacket.

Professor Ryan. Professor J. Ryan observed that the Author said (p. 178): "The steam in the cylinder at release expands down to the pressure of the condenser. The expansion takes place partly in the cylinder, partly in the passages, and will be attended by liquefaction similar to that which results from ordinary expansion." But liquefaction could scarely be expected here, inasmuch as the steam in passing to the condenser would have but little work to do. Since the "total heat" of saturated steam diminished with diminishing pressure, it might be expected that the steam, if dry at release, would become superheated on expanding into a chamber where the pressure was initially much lower than its own. The Author, p. 177, pointed out that at release the steam was "dry saturated steam." The tendency should therefore be for the steam to become superheated on passing to the condenser, not merely "by the hot walls," but by its own intrinsic excess as pressure and temperature fell. But the Author put on record the fact that the temperature as noted in the pipe was not greater than that which would correspond with the pressure in the condenser. This was what might be expected; for the superfluous heat, which would superheat the steam if it were enclosed in a dry chamber, mainly served in the actual circumstances to increase the energy of translation of the issuing steam, and ultimately to evaporate some of the water in the condenser, instead of raising the temperature of the steam very sensibly. But except in cases where the pipes were narrow, and much friction opposed the expansion, liquefaction was not likely to occur at the cylinder end. On p. 186, the Author directed attention to the "great excess of condensation in the intermediate cylinder over the high-pressure, and in the low-pressure cylinder over the intermediate." These observations discredited the views of some authorities, who persistently maintained the contrary. To recall some theoretical reasons, which he had put forward once before, why the condensation should be worse in the successive cylinders as usually constructed:—

(1) In the high-pressure cylinder the fall of temperature took place in less time, as it occurred during a portion only of the stroke. This was also a reason why a steam-jacket must be less effective on the high-pressure than on the other cylinders.

(2) The ratio of exposed metallic surface to weight of steam increased in each successive cylinder.

(3) The faces of the piston and of the cylinder-cover formed a

larger percentage of the total surface exposed to steam during the stroke in the larger cylinders; and these two faces were wholly exposed from the very commencement. At the outset, a certain weight of steam was brought into contact with larger condensing surfaces in the successive cylinders. Professor Ryan.

(4) The weight of metal involved in the thermal changes was greater in the cylinders which exposed the larger surface.

(5) The steam became wetter and wetter as it passed on, doing work.

These considerations showed why steam-jackets were more effective on the intermediate and low than on the high-pressure cylinder; as did also the greater gradient of temperature where boiler-steam was used in all the jackets, as the Author indicated. The Author calculated, p. 185, that a difference of temperature of 38° Fahrenheit would be required to cause a flow of "22,000 T.U. per square foot per hour" through the walls of the cylinder. According to the results of Forbes for iron, a difference of temperature of about 19°·7 Fahrenheit would suffice, and, according to Tait's careful work, 15°·6 Fahrenheit would be sufficient at a mean temperature of 342° Fahrenheit. Ångström's conclusions pointed to 30° Fahrenheit, but he used the highest temperature correction of the classical experimentalists. Modern results led to lower values. This was of course on the supposition that the only obstacle to the passage of the heat was the iron itself, whose conductivity was in question. He imagined, however, that the greatest obstacle was the difficulty of intercommunication of heat between steam and iron.

Mr. W. Schönheyder remarked that having shown, as early as 1871, how to correctly combine indicator diagrams of compound engines, so as to take proper account of the compression steam, he should like to state that though his method had been followed by many engineers, it was of course not the only correct one. Professor Unwin had a plan of his own, which, however, did not seem to be very convenient, as neither the compression curves nor the expansion curves were made to meet, and the relative proportions of the cards were therefore not made as apparent to the eye as they might have been. The Author had adopted a third method, which also was correct, and which had the great value of giving a clear oversight of the diagrams, and of showing the total losses very distinctly; but it had the disadvantage that the cards were more or less mutilated, and hence it was necessary to refer back to the original ones for information on many points. In the diagrams of trials 40, 35 and 41, the dark-shaded portions, representing the losses, Mr. Schönheyder.

Mr. Schönheyder. had been carried beyond the length of the actual diagrams; this gave a great increase to the area of losses, for which there did not appear to be any just reason. The method adopted of measuring the jacket-water could only give approximate results, and it would seem from the diagram of the steam-pipes that the water so measured must have included some of the condensation from the main steam-pipes. He could not see the reason why the Author should have fixed the indicators vertically, as this necessitated a bend (apparently quite sharp) in the passage for the steam to the indicator, and also a bend of the string over an extra pulley; these were all large factors in producing unreliable diagrams, and totally unnecessary evils. As the engines were claimed (p. 152) to represent "good examples of steam-engine design," he begged to say that it was not good design to bring the cylinders in line with the cross-head guides by means of set-screws, which were always liable to serious abuse; when the same end (that of securing small heat-conducting surfaces) could have been reached by providing narrow but solid strips cast on either piece and properly tooled, so that when the cylinder and guide were once made true they would always be so. Neither was it good design for valves of such abnormal dimensions, working under such high pressures, and at such high speeds, to have their rods connected to the eccentric rods by such diminutive pins as shown, and without the provision of means for taking up wear. In order to "cause the governor to close the expansion valve" (p. 162) a "Meyer" gear had been provided, several bevel-wheels, lay-shafts, friction-clutches and other gear; the same result could have been obtained in a much simpler manner, with probably one-quarter the number of parts, by a judicious use of the "Bodmer" gear, often erroneously called the "Rider" gear. The use of running joints was very properly condemned (p. 160); they were convenient appliances for jointing gas pipes or for similar light purposes, where pressures were low, where no heat prevailed, and where vibrations were absent. On p. 161 it was stated that "the air-pump .... is designed to work up to 400 revolutions per minute." This pump did not appear to differ in construction from air-pumps in use twenty-five or thirty years ago, and intended for quite moderate speeds; it would be interesting to have it more fully described, so as to show in what particular it was so well suited for high speeds. It might no doubt be reciprocated up and down at the rate mentioned, but he doubted if it would "work," that was, produce a good vacuum at even one-half or one-quarter of that speed.

17 December, 1889.

SIR JOHN COODE, K.C.M.G., President,
in the Chair.

The discussion upon the Paper by Professor Osborne Reynolds, "On the Triple-Expansion Engines and Engine-Trials at the Whitworth Engineering Laboratory, Owens College, Manchester," occupied the evening.

Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 2342.*)

"The Water-Supply of some Italian Towns."

By Alexander Fairlie Bruce, Assoc. M. Inst. C.E.

As the Author has enjoyed somewhat exceptional opportunities of obtaining trustworthy information on the subject of Italian water-supply, it has occurred to him that a sketch of the water-works of some of the principal towns of Italy may be of interest, especially in view of the anxiety now felt by the Government for the improvement of the sanitary condition of that country.

Venice.

This city was for long entirely dependent for water-supply on the rain which fell within its own area, collected in cisterns (*Figs. 1* and *2*) in the piazzas and courts. This being very insufficient, the Government of the Republic in the sixteenth century made the Seriola Veneta Canal from the Brenta at Dola to Moranzani, the nearest point of *terra firma* to Venice, whither the water was conveyed in boats and pumped from them into cisterns. The inadequacy of this supply being more and more severely felt, a concession was, in 1875, granted to Messrs. Ritterbrandt and Dalgairns for the construction of an aqueduct and the sinking of an artesian well 1,148 feet deep. They transferred this concession to the Cie. Générale des Eaux in 1879, who, after making some alterations in the original designs, commenced work in 1881, and completed the undertaking in 1883.

At a point near the village of S. Ambrogio and 60 feet above datum, a water-bearing stratum, 10 feet thick, consisting of sharp sand overlaid by blue clay, was found only 39 feet below the surface. Into this twenty artesian wells were sunk to a depth of 46 feet. The wells consist of 12-inch pipes, enclosing an inner pipe, with a copper rose at its lower end to exclude the sand. Over the top of each pipe a small vaulted chamber is built below the surface of the ground, into which the water rises freely. Each of these chambers is connected with the principal collector, which is 658 feet long. It is provided with overflow shafts at

each end, and divided by a partition up the centre to allow one-half to be used while the other is being cleaned. At one end of the collector there is a sluice-chamber with a sand-trap 20 inches

Fig. 1.

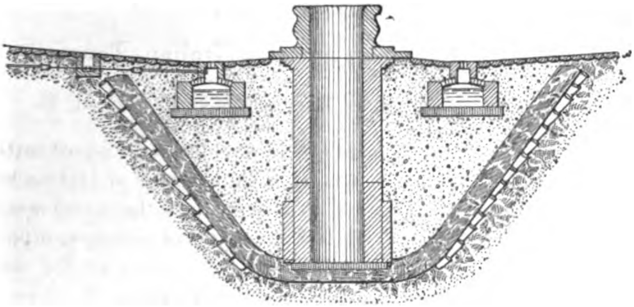
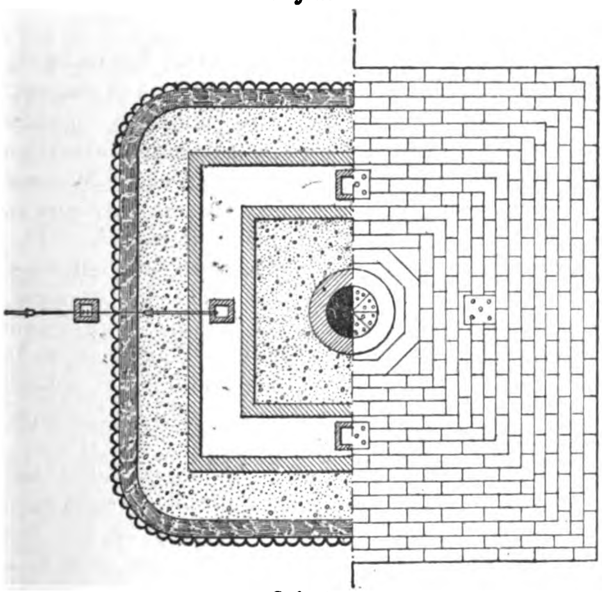


Fig. 2.



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deep, from which the supply pipe starts. The masonry is all brickwork in hydraulic mortar.

The supply pipe is 25½ inches in diameter and 16 miles long to Moranzani, laid entirely along the public road at about 6 feet

6 inches below the surface. It is made of Grenoble cement, sand, and fine gravel, 4 inches thick, surrounded with concrete composed of lime, pozzolana, and broken stones, and is capable of delivering 3,000,000 gallons a day, or 22 gallons a head, nearly three times the quantity considered sufficient in Venice. It is provided with shafts 1¼ mile apart for overflow and scouring purposes; they also afford means of access to the aqueduct, and enable each section to be isolated for repairs if necessary.

In order to admit of the water of the Seriola being used if required, four filtering-beds have been constructed at Moranzani, having an area of 1,360 square yards. The filtering materials consist of a layer of 2 feet 8 inches of sand, 2 feet of gravel, and 1 foot 4 inches of broken stones, 6 feet in all, the floor being of concrete; the rate of filtration is 18½ cubic feet per square foot per twenty-four hours, with a head of 3½ feet.

To enable the pipes to deliver 2,500,000 gallons at tidal water-level 10 feet above datum, or 4,500,000 at 6½ feet above datum, in the service reservoir at Venice, the water is raised from 12 feet, the level at which it stands at Moranzani, to 16½ feet by a rotary pump driven by a Girard turbine, which is actuated partly by water of the Naviglio Mira-Moranzani, and partly by the overflow from the Seriola Canal. The water is pumped into a caisson, with a capacity of 7,700 gallons, from which the pipe to Venice starts. In case any accident should happen to the pump, provision is made for introducing the water directly into the pipes from the filters.

The pipe to Venice is of cast-iron, and is laid below the lagoons; it is 31½ inches in diameter, and has a total length of 4 miles. The depth, except where canals are crossed, seldom exceeds 4 feet. The pipes were laid within cofferdams (*Figs. 3* and *4*); they have a cover of 20 inches, and are supported on piles. At the crossings of the Donena and Scomenzera canals, where the depth of water and current are too great to admit of the pipes being laid in this way, divers were employed. The pipes were jointed throughout with rings of vulcanized india-rubber 3⅞ inches deep, not a very durable description of joint. It appears to the Author that this work might have been quite as efficiently, and considerably more economically, done by using lead joints with a ball-and-socket arrangement between every two ordinary joints, which could have been made on a barge and launched out by degrees. They could have been sunk to the required depth in the mud by dredging; supporting piles appear to have been scarcely required.

A vertical pipe, 4 feet 1 inch in diameter, is placed every $1\frac{1}{4}$ mile to allow of inspection. These pipes are protected from damage by

Fig. 3.

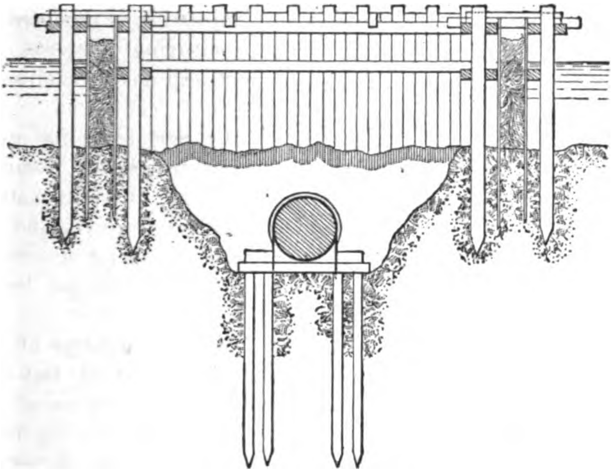
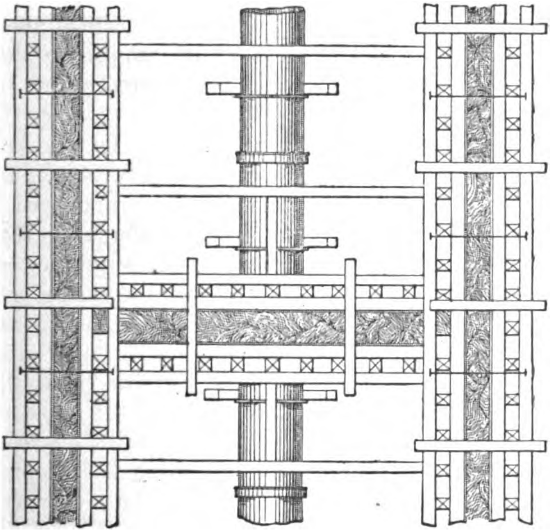


Fig. 4.



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passing boats by a ring of piles. The pipe is laid below the railway station in a gallery to the service reservoir at S. Andrea.

This has a capacity of about 2,250,000 gallons, supposed to be sufficient for two days' consumption. It is divided into three independent compartments, consisting of a central division 23¼ feet wide, spanned by a single arch, and two, one on either side, 92½ feet wide, covered with vaulting of about 12 feet span; the length of all three is 111¼ feet and the depth 16·4 feet. It is founded on 8-inch piles, spaced 23 inches apart from centre to centre below the walls and 30 inches below the floors, which are covered with concrete 3 feet 7 inches thick. The walls are of brickwork 6 feet 8 inches thick at the bottom and 3 feet 11 inches at the top, with counterforts 3 feet 11 inches by 3 feet 4 inches every 15 feet 3 inches; the internal partitions are 5 feet 10 inches thick. The whole interior is rendered with Grenoble cement, and it is provided with ventilating shafts.

The water is pumped from the reservoir direct into the supply pipes by four Girard pumps, driven by two engines of 32 effective HP., capable of delivering 1,100,000 gallons in twelve hours' pumping, while a third pair of pumps is kept in reserve.

An accumulator is placed between the pumps and the distributing pipes, consisting of a vertical cylinder 48 inches in diameter, in which a heavy cast-iron piston works, and which can be loaded up to any desired pressure. The admission valves of the engine being connected to the piston-rod, when the pressure in the pipes becomes too low the piston falls, admitting more steam to the steam-cylinder, and *vice versâ.* The piston has a range of 15 feet, and it cuts off the steam before it reaches the top of its run.

There are about 9 miles of distribution pipes, of diameters varying from 15¾ inches to 5⅛ inches, and about 16 miles of private pipes of from 1 inch to 2⅓ inches in diameter; there are eighty-six siphons below the canals, feeding one hundred and twenty commercial cisterns besides private supplies.

Genoa.

The city of Genoa was till the fifteenth century exclusively dependent on its own internal resources for water-supply. About that period the Government of the Republic, then at the height of its power, constructed a masonry aqueduct, which conveys the water of the Bisagno from a point 10 miles from the city and 500 feet above the sea; its tributary, the Concasca, was afterwards connected by a branch. The aqueduct is still a fine work, though now somewhat dilapidated; indeed, in some places it has been reconstructed two or three times on as many different lines as each

in turn became irreparable. At two points long iron siphons supported on arching, more monumental than useful, have been erected to avoid former long detours round the valleys of tributary torrents. But though considerable sums are spent annually on repairs, there is still a loss of about 30 per cent. of water due to leakage and theft by the way. In summer, according to the Author's gaugings, about 4,000,000 gallons of water are taken in daily, but only about 3,000,000 gallons reach Genoa. The aqueduct is partly covered and partly open, which is a fruitful source of pollution, as are also several mills built over and driven by it. It arrives at Genoa at a height of about 250 feet, and is distributed to the various owners of water rights by means of lead pipes; in some streets there are six or eight of these laid side by side.

About twenty years ago the Nicolay Company was formed to bring an additional supply from the River Scrivia, near Busalla, by means of an infiltration gallery, whence the pipes are laid through the well-known Giovi Railway tunnel, in return for which privilege the company gives the railway free of charge 10 per cent. of the total supply of water necessary for the railway stations between Busalla and Genoa. In addition to the Giovi tunnel there is a total length of 2,500 yards of tunnels through the spurs of the Appenines. According to official documents the Company gives 211,000 gallons of water daily free to the Municipality, and altogether it is said to be able to deliver nearly 12,000,000.

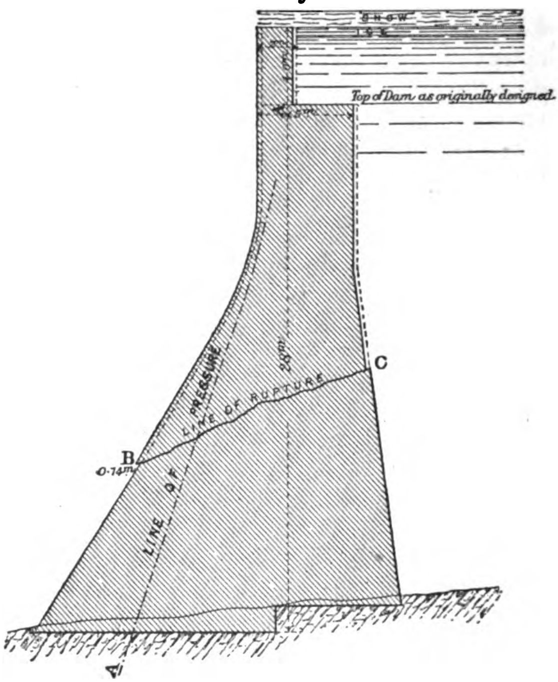
The works of the Gorzente or Deferrari-Galliera Company are of still more recent date. They have their source at the Torrent Gorzente to the west of Genoa, where there is a storage reservoir holding about 220,000,000 gallons. The dam is 102 feet in height, 196 feet long, and 16 feet 5 inches wide at the top. It was originally designed to be only 89 feet high, but after completion the engineer added a parapet 13 feet high and 6 feet 6 inches thick. The reservoir was allowed to fill rapidly before the mortar, which was of inferior quality, had properly set. The width of the waste-weir being insufficient, the water rose to the top of the dam; a hard frost then set in forming a thick coating of ice, on which 2 feet of snow fell. The dam burst soon after, as shown by *Fig. 5*, the upper portion moving 6 inches outwards. The line A A shows the probable line of pressures at the time of rupture, when, according to the Author's calculation, the positive or compressive strain at B must have been about 172 lbs. per square inch, and the tensile or negative strain at C 71 lbs. per square inch, which is more than double what even masonry of the best quality may be safely counted on to resist. This dam has now been reconstructed.

The main is of cast-iron 24 inches in diameter, and is said to be capable of delivering 13,000,000 gallons daily; a supply of 105,000 gallons daily is given free to the Municipality, of which a considerable part is used to generate 800 HP. for electric lighting.

Both these companies have canalized the whole city, and also supply Nervi and some of the villages round Genoa.

In addition to the existing companies, an English company, for

Fig. 5.



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whom the Author acted as Resident Engineer for fifteen months, is making works with the view of exhausting the powers of supply of the Bisagno and Concasca basins, from which a further yield of 4,000,000 gallons daily is anticipated. These works, when completed, will consist of two storage reservoirs to contain 300,000,000 gallons, a service reservoir with a capacity of 6,000,000 gallons, and about 8½ miles of main piping 22 inches and 24 inches in diameter, and 20 miles of canalization in the town.[1]

[1] Since the Paper was written the Company has been wound up, and the works have been stopped, owing to financial difficulties.

The price usually charged for water in Genoa, for purchase in perpetuity is £480 per oncia of 4,224 gallons a day, or 2*d.* to 4*d.* per 1,000 gallons measured through an adjusted tap, and about 1*s.* per 1,000 gallons if by meter, according to the elevation.

Rome.

From the most ancient time Rome has possessed the best water-supply in Italy. At present Rome receives water from four aqueducts, three of these of great antiquity, namely, the Vergine, Felice, and Paolo; and from a more modern or rather an old work resuscitated, called the Acqua Marcia, or Pia, aqueduct. The three former are owned by the Municipality; these yield nearly 34,000,000 gallons daily, and are leased by the company, who reconstructed the Acqua Pia, at 0·09*d.*, 0·20*d.*, and 0·16*d.* per 1,000 gallons respectively.

The Acqua Pia is capable of delivering 19,750,000 gallons daily, so that Rome has a total supply of nearly 53,500,000 gallons per day, or about 200 gallons per head, which no doubt partly accounts for it enjoying the smallest death-rate of any continental capital.

The Acqua Marcia springs, which were brought into Rome in very early times, acquired a great reputation for excellence; but the aqueduct, from want of repairs, became useless. In 1870 a society was formed, and obtained a concession from the then Papal Government to reintroduce the water of these springs into the city.

The Acqua Marcia consists of three groups of springs called "serene," which derive their supply from water collected by a marl formation known as the Campo Secco, near the sources of the Aniene, which rises to an elevation of 4,200 feet above the sea. The three serene are said to be capable of yielding 64,000,000 gallons per day. They are each collected in a separate well, from whence they are led in a covered channel to the main aqueduct, into which they can either be introduced or allowed to flow to waste.

The total difference in elevation between the source and the service reservoir is 430 feet; of this 366 feet are exhausted in various falls and the remaining 64 feet in the gradients, which are $\frac{1}{1.000}$, $\frac{1}{2.000}$, and $\frac{1}{4.000}$, the average being $\frac{1}{1.370}$. The dimensions of the section of the aqueduct are: a constant depth of 2 feet 11½ inches, with widths of 2 feet 8¾ inches, 3 feet 4½ inches, and 4 feet 0½ inch, according to the gradient; the depths at the springing

are: 4 feet 7 inches, 4 feet 9 inches, and 4 feet 10 inches, and the whole wetted perimeter is rendered with cement.

According to Darcy's formula, the daily discharges for these sections should be 25,052,000 gallons, 21,893,000 gallons, and 20,424,000 gallons respectively; the actual unrestricted discharge is said to be 25,340,000 gallons, or 1 to 19 per cent. in excess, which must be due to the increase of velocity at the falls. It is proposed to utilize the power at present going to waste at the falls, amounting to 1,550 HP., to raise water for the supply of many small places above the level of the aqueduct at present unprovided.

There are a few bridges, but most of the streams are crossed by iron siphons. There are several settling ponds at different points 100 feet long, 30 feet wide, and 12 feet deep, provided with two weirs, over the second of which is placed a wire-gauze screen to intercept floating matter; they have also grooves for the admission of stop-planks, by which the water can be turned into the Aniene for cleansing and repairs.

The walls of the aqueduct in the trench are 16 inches, and on bridges and exposed positions 19½ inches thick. There is a length of 7½ miles in ordinary excavation, and an equal length in tunnel. The bridges, of which there are nineteen, retaining walls, &c., account for 1¾ mile, making 16¾ miles in all.

The reservoir of Quintus Varus, at Tivoli, holding 214,000 gallons, has been made use of as a service reservoir, and the cast-iron pipes start from it. The pipe from Tivoli to the Piazza Mosè, where the pressure regulator is placed, is 24 inches in diameter, and 16¾ miles long. The maximum head of water is 559 feet, and the highest point supplied 260 feet above sea-level.

Most of the houses have cisterns containing 400 to 500 gallons. The price charged per meter is 3¼*d.* to 5¼*d.* per 1,000 gallons, and for absolute purchase £76 to £123.

There still remain many important towns in Italy practically without water-supply or drainage, which would offer considerable scope for the profitable investment of capital, if the works were carried out with reasonable regard for ordinary commercial principles, the reckless disregard of which has led to the ruin of more than one promising undertaking. Work can be done in Italy at prices which, with the exception of ironwork, are considerably below those ruling in Great Britain, owing chiefly to the cheapness of labour: a mason receives about 3*s.*, a quarryman, 2*s.* 3*d.*, and a navvy, 2*s.* per day; building stone and lime can be obtained nearly everywhere. Good hydraulic rubble masonry can be built

for 8s. 6d. to 12s. per cubic yard; ordinary excavation costs about 8d.; rock, 1s. 6d. to 2s., and tunnelling, 3s. to 4s. per cubic yard, and cast-iron pipes cost £7 10s. per ton.

The errors usually fallen into by English companies who have done work in Italy and Spain, are those of buying concessions without proper investigation of the conditions involved, or the laws to which they are subject, and of investing much too large a capital to offer any prospect of profitable return. It is generally mere waste of money to provide 25 gallons to 35 gallons of water daily per head for a southern town, when the people have been accustomed to use only 4 gallons or 5 gallons; 10 gallons to 15 gallons will usually be found quite enough to introduce in the first instance, the works being designed with a view to expansion, when the people have been educated up to an increased consumption.

The unit of measurement commonly adopted in Italy is the "oncia," equal to 4,224 gallons per day; and water is either sold in perpetuity or leased for a certain number of years. About 1s. per 1,000 gallons is usually charged for water sold by meter, and a fourth of that price if measured by means of an orifice, as it is not supposed that the consumers will draw for more than three or four hours per day. In the older works, the method of measurement used is to admit the water from the aqueduct into a small cistern divided into two parts, with an orifice in the partition, over which the head is maintained nearly constant, equal to that which is found by experiment to give the required discharge, and each consumer has his own private lead pipe.

For most of the facts relating to the water-works of Venice the Author is indebted to Mr. Lavezzari, the Engineer for the works. The statistics of the reservoir and works at Genoa have been supplied by Mr. Botto, the Contractor. While Mr. A. Filonardi, the Engineer and Manager of the Acqua Marcia Company and Director of the Società Italiana, Rome, has furnished the Author with the information concerning the water-supply of Rome and the towns mentioned in the annexed Table, except Florence, for which the authority is Dr. Coldstream; Naples, Mr. Blake, the Engineer; Verona, Mr. Lavezzari; and Turin, where the Author made enquiries on the spot.

The Paper is accompanied by diagrams, from which the *Figs.* in the text have been reduced.

Name of Town.	Population Supplied.	Length of Main.	Quantity of Water Supplied.		Cost of Works.			Source of Supply.
			Total.	Per Head.	Total.	Per Head.	Per 1,000 Galls.	
		Miles.	Gallons.	Gallons.	£.	s. d.	d.	
Agnone	8,784	3·00	99,790	11·36	5,528	12 7	3⅞	
Albano Laziale	6,560	5·40	133,436	20·36	9,337	28 5	4⅞	
Alessandria della Rocca	5,786	0·17	89,338	14·44	333	1 9	0¼	
Camerino	4,342	3·30	66,528	15·32	4,575	21 1	4	
Castellermini	9,205	5·60	190,080	20·64	15,554	33 9	5½	
Cattolica Eractea	6,591	4·50	28,512	4·32	7,231	21 11	16⅞	
Caltagirone	28,119	4·66	209,088	7·44	32,400	23 1	10¼	
Civitavecchia	9,210	11·14	264,000	28·66	15,960	32 8	3¾	
Cori	5,450	9·30	52,800	9·69	11,426	50 0	16¾	
Florence	162,500	1·00	3,250,000	20·00	..	..	⅓ to 2[2]	Well sunk in old infiltration gallery.
Genoa	300,000 (cir.)	..	26,000,000	86·00[1]	..	..	2 to 12[2]	Infiltration gallery, &c.
Leghorn	120,000	..	386,000	3·20	..	..	..	Old aqueduct from Pisan Hills.
Macerata	10,063	18·40	266,112	26·45	35,000	69 7	8¾	
Marino	6,071	2·50	209,088	34·43	6,470	21 4	2	
Naples	500,000	37·50	22,000,000	44·00	..	..	..	Spring in gallery.
Nicastro	13,537	2·75	96,500	7·13	6,360	9 5	4⅓	
Potenza	17,978	7·67	145,200	7·97	18,579	21 9	9	
Rome	267,000	33·50	53,500,000	200·00	..	..	3½ to 5½[2]	Springs.
Tagliacozzo	7,250	2·50	133,000	18·35	3,136	8 8	1½	
Trapani	32,020	41·50	928,400	29·00	128,000	79 11	9	
Turin	259,300	12·00	1,750,000	6·75	..	..	12	
Venice	136,300	20·00	3,000,000 1,100,000	22·00 8·00[3]	..	..	..	Filtration gallery.
Venosa	8,014	1·25	85,600	10·69	1,211	3 0	9	
Verona	..	1·00	1,480,000	..	..	..	..	Filtration gallery.
Viterbo	15,800	2·50	361,200	22·86	2,089	26 5	3¼	

[1] These figures are of doubtful accuracy; the quantity really available appears to be only about one-fourth.
[2] Price charged to consumers.
[3] The quantity actually supplied.

(*Paper No. 2406.*)

"Hydraulic Packing-Presses."

By CHARLES HOPKINSON, B.Sc., M. Inst. C.E.

THE packing of cotton piece-goods for export is a characteristic trade in Manchester. The appliances used in the process are of considerable magnitude, though not comparable to the enormous forging-presses now used, and are of interest as an illustration of that gradual mechanical development which is a feature of this century. Probably, however, they have not come under the notice of many members of the Institution.

The number of packing-presses in Manchester is not far short of five hundred, and the accessories to these presses include many separate installations of steam- and gas-power pumping-plant with accumulators and hoists.

In the earliest days of hydraulic packing the press-rams were from 6 to 10 inches in diameter, supplied by hand-pumps, to which power was first applied some fifty or sixty years ago by coupling a revolving crank and the hand-lever with a connecting-rod. Twenty-five years ago the prevailing sizes of press were from 9 inches to 14 inches in diameter, worked at a pressure of 2½ tons to 3 tons per square inch, giving a maximum squeeze on the bale of 460 tons. The only material then available at reasonable cost for making the cylinders was cast-iron, and the pressures used were as great as the nature of the material permitted. The 14-inch press cylinder, with a thickness of 10 inches, was stressed in its innermost layer to over 4 tons per square inch. Frequent breakages demonstrated that the stress was too great. The deficient strength of the cylinder could not be increased by adding more metal, as it was found in practice that if a greater thickness were employed the metal was less homogeneous, and that the increase of strength expected on theoretical consideration was not obtained. The stress could not be reduced by increasing the diameter of the cylinder used for a given squeeze, from considerations of external size which was occasionally limited by the openings into the warehouse basements containing the presses. Whilst this difficulty of providing the pressing power was felt, there was a constant desire on the part of exporters to pack tighter and tighter, so as to ship

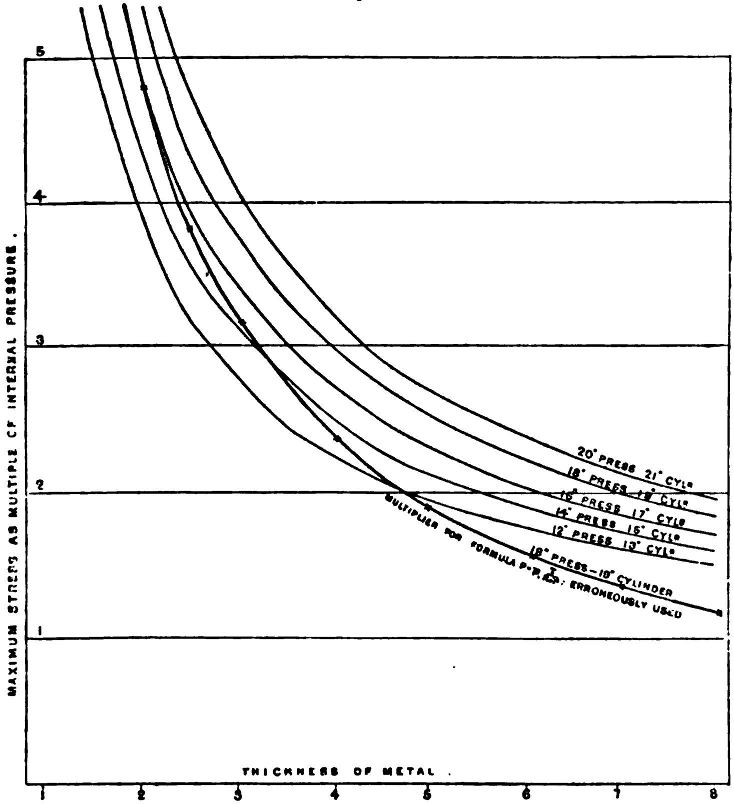
more goods in the same bulk, and thus obtain a practical reduction of freight charges. The conditions fixing the limited squeeze were altered by the introduction of steel. This material, after a period of hesitation and doubt, is now thoroughly established for packing-press cylinders, and its use has enabled the maximum gross squeeze to be increased to 700 tons with a substantial factor of safety, as against the old squeeze of 460 tons with a vanishing factor. The present maximum squeeze is not likely to be further increased; already the freight measurement is exceeded by the dead weight, that is, 40 cubic feet measure of bales weighs more than 1 ton, and by some shippers the pressure is considered detrimental to the appearance and quality of the cloth.

The press cylinder is made of cast-steel with an ultimate tensile-strength of 25 to 35 tons; the usual thicknesses are, for a 14-inch cylinder $2\frac{3}{4}$ inches, and for an 18-inch cylinder $3\frac{1}{4}$ inches, giving (by formula $p\,\frac{R^2 + r^2}{R^2 - r^2} = P$, when $P =$ the tension per square inch on the inner layer, R and r the outer and inner radii, and p the pressure in the cylinder) a maximum stress of 9 tons on the inner layer of a 14-inch cylinder when worked to $2\frac{3}{4}$ tons, and a slightly higher stress with the 18-inch press worked to the same pressure; but, as the 18-inch presses are seldom worked beyond $2\frac{1}{2}$ tons on the square inch, the margin of strength is proportionately increased (*Fig. 1*). Some makers determine the proportions of the cylinders by the average stress, taking the total bursting-pressure on the area of steel sustaining the stress; say, on an 18-inch press, $19 \times 2\frac{3}{4} = 52$ tons on an area of $6\frac{1}{2}$ square inches $= 8$ tons on the inch—a considerable discrepancy as compared with the 9·6 tons of the formula. The water is admitted centrally through the bottom. The old method of entering through the side of the cylinder led to fractures, and is now discarded. The upper part of the cylinder is bored for a length of 12 to 18 inches to fit the ram, and form its guide, the lower part of the cylinder being cast large enough to clear the ram and give an annular space for the water. A recess, about 2 inches long, varying from $\frac{1}{2}$ inch to $1\frac{1}{4}$ inch in radial depth, is bored in the guide part to receive the leather packing, which is of ∩ section. The practice of different makers varies as to the form of the ∩; some engineers making the sides of the ∩ to touch, others leaving them as much as $\frac{3}{4}$ inch apart. The close ∩ seems to give the best results, being stiffer in the bend, and therefore better able to resist deformation and its consequences, namely, increased friction and liability to seize. Proposals have been made to support the bend

with a rigid support, but the close-sided ∩ is a simpler method of arriving at the same result. The upper part of the cylinder is enlarged in the usual way to form a supporting collar, which rests on the press bottom.

The pillars, four in number, which act as supports for the press top and as bolts to resist the pressing force of the ram, are forged of wrought-iron, or occasionally steel, turned with great care to an

Fig. 1.



equal length, so that the pressure is taken equally amongst them. The variations of load on the different pillars, due to irregular placing of the goods before pressing, are small as compared with the strength of the pillars, and are neglected in practice. The prevailing diameter for an 18-inch press is 7 inches, giving a stress of about 4·5 tons per square inch. The pillars are usually turned

with swells to receive pressure from the press top and bottom. Nuts are rarely used by Manchester press makers, the pillars being inserted in recesses formed to receive them.

The press tops and bottoms, which are in effect beams, are always made of cast-iron. The tops were originally constructed with a continuous bottom flange or plate forming a plane surface for pressing against, and strengthened by ribs running lengthwise of the top. The beam was thus unnecessarily strong in resisting compression, but weak as against tensile-stresses; many failures resulted from this arrangement of metal, and the form was altered, first, the Author believes, by Mr. John Hopkinson, by the introduction of a continuous top flange, thicker than the under flange. A compound beam is thus formed, of which the proportions have been determined by practice. If a maker found his press tops to fail he strengthened them in the places indicated by the fracture, and thus gradually evolved a form which survives. The press bottoms had a somewhat similar history; the bottom continuous flange was early introduced for the press to rest on, and the difficulties were rather with the replacement of the strength which was taken away by the large central hole for receiving the cylinder. With cast-iron cylinders this was required to be from 30 inches to 36 inches in a 14-inch press. The pillars are held in the press top and bottom in bored sockets, with openings and cover-plates; faced projections enable the pillar swells to bear normally and equally.

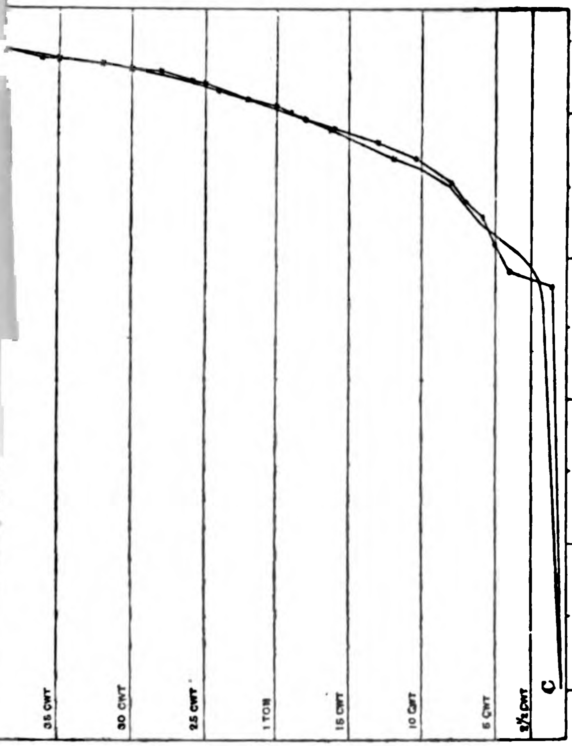
The ram acts under simple compression, and is made very massive. To avoid corrosion, and to reduce friction, the upper part is usually cased with a turned and bored brass hoop from 42 to 48 inches long, or covered with copper by electric deposition, a method introduced by the Broughton Copper Company under Wilde's patents. The table or platen has had a history somewhat similar to the press top. Failures have led to increased proportions, and now in the larger presses it is of very substantial dimensions. The table is guided by four rollers, for which the turned pillars form a path. Rollers are fixed under the table to facilitate the removal of the table for renewing the packing leather.

The various methods in use for supplying the water under pressure to the presses, may be divided into two classes:—

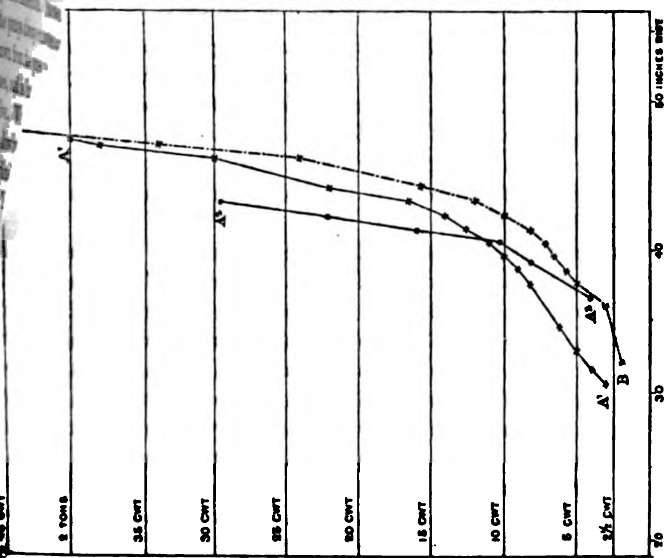
1. Engines running at constant speed, and driving independent pumps.

2. Direct-acting pumps.

The majority of the older plants have a pair of high-pressure non-condensing engines, running nominally at constant speed,



RISE of TABLE and CORRESPONDING GAUGE-PRESSURE for TWO SUCCESSIVE BALES.



RISE of PRESS-TABLE and CORRESPONDING GAUGE-PRESSURE.

A^1A^1 60 pieces, A^2A^2 same 60 pieces and 10 unpressed pieces, BB 65 pieces.
Vertical scale gives pressure, horizontal scale movements of table.

extent; further, by using the accumulator as an engine-regulator, the losses of running at full speed, when little or no work is being done, are very largely diminished.

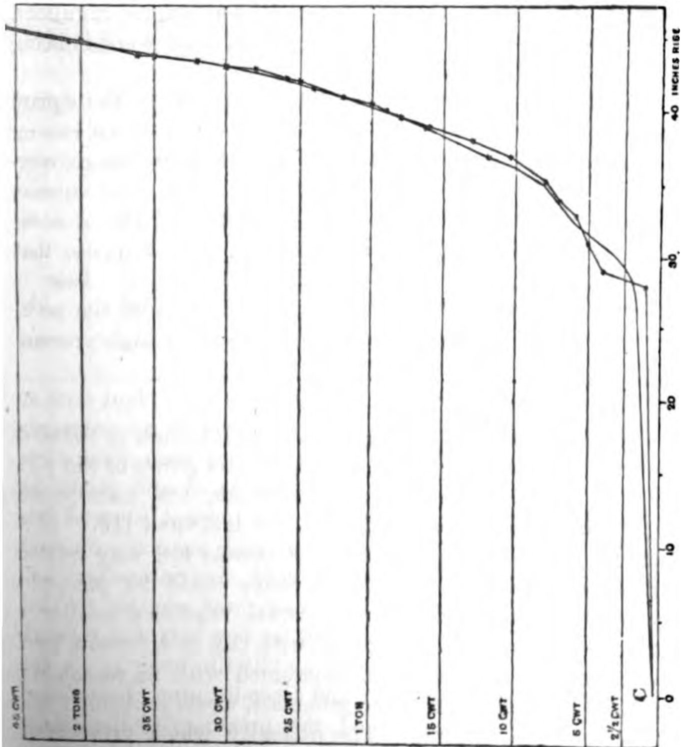
The standard accumulator pressure is 1,120 lbs. to the square inch, and with this pressure sufficient force is provided for raising the press-table through from 78 to 88 per cent. of its range, compressing the bale to a considerable extent. The final squeeze is given by the pumps. There is occasionally a waste of accumulator water if a plant is not fully occupied. Suppose that the accumulator is filled by the pumps before the bale is completely pressed or "set," water must be let off from the accumulator to keep the pumps going for the supply of high-pressure water.

The convenience and saving of time in working a plant with an accumulator are undoubted, but the arrangement as ordinarily worked is not economical, as water which has been pumped to ½-ton pressure is used for lifting the ram, table and goods, for which 80 or 100 lbs. would be ample. To prevent some of this waste, and to secure the advantage of pumping against a constant pressure, Mr. Bellhouse has introduced an intensifier and diminisher,[1] which, in its original form, was similar to that described by Mr. R. H. Tweddell,[2] but is now adapted to work first as a diminisher, producing water at 224 lbs. pressure for the early stages of the lift of the ram; and secondly, after the accumulator ½-ton pressure has continued the pressing, another stage coming in as an intensifier to give 2½ tons pressure on the square inch.

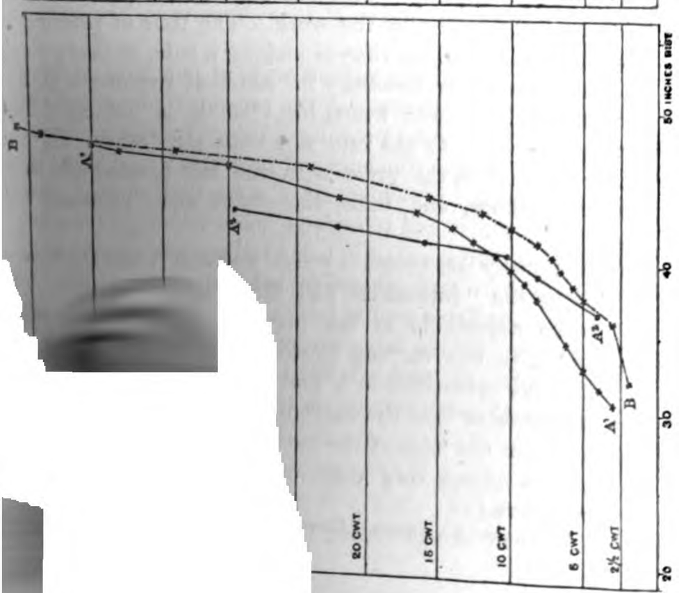
The relative economies of the various ways of pumping are best compared by exami[illegible] a diagram of the pressures corresponding to the travel of [illegible] whilst pressing a bale. In *Fig.* 2, curves A^1A^1, A^2A^2, [illegible] and pressures whilst packing a bale of [illegible] sixty were first pressed, the press th[illegible] pieces more added; BB represent s[illegible] bale of sixty-five pieces; and in *F*[illegible] essive [illegible] another class of g[illegible] lts fro[illegible] grams, neglecting [illegible] rge re[illegible] ure from 28 to 31 [illegible] ves, w[illegible] ntly due to the [illegible] comi[illegible] ly:—

[1] [illegible] iii. p. 567, for a simila[r] [illegible]

[2] [illegible] ngs. 1874. p. 168.



RISE of TABLE and CORRESPONDING GAUGE-PRESSURE for TWO SUCCESSIVE BALES.



RISE of PRESS-TABLE and CORRESPONDING GAUGE-PRESSURE.

A^1A^1 60 pieces, A^2A^2 same 60 pieces and 10 unpressed pieces, BB 65 pieces.
Vertical scale gives pressure, horizontal scale movements of table.

—	Net Work.	Net Work used from Accumulators and Constant-power Pumps.	Net Work used by Diminisher, Accumulator, and Intensifier.	Gross Pump-power varied to suit Load.	
				80 per cent. efficiency.	75 per cent. efficiency.
	Foot-tons.	Foot-tons.	Foot-tons.	Foot-tons.	Foot-tons.
$A^1 A^1$	225	714	466	281	300
$A^2 A^2$	68	411	186	85	91
$A^1 A^1 + A^2 A^2$.	293	1,125	632	366	391
B B	258	730	461	323	344
C C	325	843	618	406	433

The time occupied in a single compression, such as BB or CC, varies with the character of the goods and the power of the plant; about one minute would be the minimum, the corresponding average rate of work used would be 57·2 indicated HP. It will be seen from the Table that the best results are very wasteful, and that a system by which the water could be pumped at the pressure at which it is used would require a smaller net power to be delivered as compared with the best present results from direct-acting pumps, and, if combined with an economic use of the high-pressure steam in the generator, would probably amount to 60 per cent. of saving. The difficulty which prevents this saving is the irregularity of the work. The time of pressing is about one-ninth of the whole time of making a bale, so that a plant of at least nine presses is necessary for constant running if multiplication tended to a true averaging, but it is not so. The tendency is for presses to get into step with each other. Of two presses rising together, the press with the less pressed bale in it offers least resistance, and takes the water until pressures are equalized.

The other remedy suggested to this wasteful working is in a development of the "intensifier and diminisher" principle. If arranged to be adjustable to the pressure, a constant-pressure supply would give the varying pressure required. To produce such a differential intensifier is a problem for the inventor, who will need to remember that the convenience of the wasteful system, and its economy in the time of the packers, will enable it to maintain its position unless very great improvements in mechanical efficiency are arrived at.

The magnitude of the pressures prevents the convenient deter-

mination of the friction at high pressure; but for low pressure, depending entirely on the weight of the ram and table, it is easy to obtain approximate results by gauging the pressure with the ram when rising and when falling. The differences so obtained by the Author vary from 2 to 5 per cent., giving a coefficient varying from 1 to 2½ per cent. Taking into account the circumstances of the various readings, the Author would place the actual coefficient for low pressures and low speeds at about 1·25, or rather higher than Mr. Tweddell, who gives 1 per cent. as the loss by friction in using water-pressure in well-constructed plant in good order. For high speeds, the friction in the pipes and the difference between cylinder-pressure and gauge-pressure prevent any accurate determination in this way.

Steel piping is now always used for the high-pressure supply, not only because of its superior strength, but also for its greater power of withstanding corrosion and furring by oxidation. With accumulator plants, separate piping is used for coupling the accumulator and presses with a simple stop-valve to each press; the higher pump-pressure is regulated by a double-stop or three-way valve, which couples the high-pressure supply to the press or allows the water to pass on to the piping beyond. The same stop, by another handle, couples the press to waste.

The Paper is accompanied by three diagrams, from which the *Figs.* in the text have been prepared.

(*Paper No. 2414.*)

"Jetties as applied to Harbour Entrances in the United States."

By Professor Lewis M. Haupt, M. Am. Soc. C.E.

Although nearly four centuries have elapsed since the Latin and Anglo-Saxon races disembarked on the shores of America, yet but little more than a score of years has passed since the inauguration of a systematic method of river and harbour works by the United States Government.

In so brief an experience engineers would scarcely expect to find many completed structures or valuable precedents, yet the shores of America are not devoid of instructive lessons.

Naturally, however, Americans turn to the old world, so pregnant with great and durable examples of maritime works, for precedents, and for successful applications of general principles, and hence it is that the earlier European methods of jetties and dredging have been adopted.

The resources of the profession are stated, in a report on the harbour of Galveston, Texas, to be limited to the two methods—(1) "by dredging alone; (2) by using tidal scour between jetties, aided, if necessary, by dredging;" and it is added, "As to the first it has already been tried unsuccessfully." This narrows the choice down, then, to a single system, namely, that of jetties, for effecting tidal scour. Hence it may be inferred that the instances of the successful application of this system, under similar conditions, must be very satisfactory to justify the expenditure of more than \$8,000,000 (£1,600,000) in its application at this locality. Is this the case? For a reply, the physical conditions existing at other sites where jetties have been or are now being attempted should be examined.

The elements involved are the fresh-water volume, tidal-prism, wave-action, winds, currents, shore-line, and character of the material. The action of these several forces and elements in modifying one another will be greatly influenced by the form of the basin or mould of the submerged ground over or within which they act. They are interdependent and sustain to each other the relations of cause and effect, leading to intricate combinations of many variables, which it is hopeless to attempt to formulate

mathematically. The conditions may, however, be readily grouped with reference to the preponderating features. Thus there will be observed a class:—

1. In which there are tidal fluctuations of considerable magnitude with but small interior reservoirs and little or no fresh-water drainage; or,

2. The tide may be great and the inner lagoon or sounds large, while the land drainage is insignificant; or,

3. The mean tides may be small, not exceeding a few feet, while the interior bay may be extensive; or,

4. There may be no intermediary settling basin, and the rivers, whether great or small, may debouch directly into tidal waters; or,

5. They may empty into tideless seas or lakes, in which case it will be observed that the mouths are, as a rule, of deltaic formation rather than estuarian.

By an examination and classification as above of the conditions prevailing at those places where jetties are found to have been satisfactory, the engineer may discover where their use may be resorted to with reasonable prospect of success, and much time and money may be saved.

It may appear presumptuous in the Author to state that he has been unable to find a single instance "at home" where convergent jetties have resulted in securing a permanent improvement. It is true there are a few instances where the incomplete structures have modified the currents and resulted in changing the position of the bars, at the same time reducing their depth several feet during the transition stage; but the conditions of the channels are unstable and formative.

Probably the case where the greatest improvements have been effected is that at the mouth of the St. John's River, Florida,[1] where the least depth of the channel has changed from 5·8 feet to 13·2 feet in three years; but the crest has advanced seaward about 2,200 feet, and the exterior slopes have changed from convex to concave. The officer in charge states that "until the very rapid changes, caused by the opening of the channel between the jetties, have ceased, and a somewhat normal condition shall have been re-established, deductions as to the stability of the deep channel across the bar cannot be fairly made. These results will not be permanent until the jetties have been extended to their full length and given a permanent cross-section."

[1] Annual Report of the Chief of Engineers, U.S. Army. 1888. Part II. p. 1080 *et seq.*

"The approved project is to obtain a least mid-channel depth across the bar of 15 feet at mean low water by the contraction of the stream by two long jetties, starting from the opposite shores of the entrance and converging until, near their outer extremities on the bar, they shall be 1,600 feet apart. The jetties are to be built of brush or log mattresses and rip-rap stone, and suitably capped. The estimated cost of this improvement is $1,306,409 (£261,282). The usual low-water depth on the bar before the work was begun varied from 5 to 7 feet, with a mean rise of tide of about 5 feet. The channel across the bar shifted from time to time, north and south, through a distance of about a mile. Since the adoption of the present project, in 1879, five appropriations have been made by Congress for the work, aggregating $675,000." The total amount expended to the 30th of June, 1888, was $670,957·13.

The total lengths of the unfinished jetties at this date were, for the south jetty, 6,667 feet, of which 4,100 feet out from the shore end were built to and above the level of mean low-water. The remainder had its crest about 6 feet below low-water. For the north jetty, 6,585 feet, of which 553 feet were at full height and capped, and 5,079 feet were at the height of mean low-water. The rest was from 0 to 10 feet below.

The physical conditions at the mouth of the St. John's would place it in group (4), having no interior basin but discharging directly into tidal waters, and hence a favourable position for improved results, although, as stated, the increased depth cannot be regarded as permanent.

There are other less successful experiences with convergent jetties in the United States, and one in which a modified plan of submerged convergent jetties was tried, which contains some important suggestions.

The deepest channel across the bar at Charleston, South Carolina, is about 7 miles south of the gorge between the islands, and its greatest available depth is only 12 feet. By the project, approved in 1878 and estimated to cost $3,000,000 (£600,000), it was intended to secure 21 feet of water, at a point directly in front of the gorge, by two jetties, designed to admit the flood-tide freely by submerging their shore ends, and to train the ebb currents across the bar by raising their outer extremities to or above the surface.

The initial report on the project states:—[1]

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[1] Annual Report of the Chief of Engineers, U.S. Army. 1878. Part I. p. 563 *et seq.*

1. "The north jetty will reduce the half-tide area of the water-way from its present area of 78,880 square feet to 41,593 square feet (47 per cent.)."

2. "The south jetty half-tide water-way will be reduced from the present area of 201,365 square feet to an area of 94,684 square feet (53 per cent.)."

3. "In the gap," between the jetties, "where alone erosion can take place, the present mean half-tide water-way is 29,572 square feet, and the mean low-tide area 22,840 square feet."

4. "After the jetties shall have received their maximum scour, aided by dredging or other artificial appliances wherever clay-beds are encountered and the equilibrium of flow is resumed, the original average slope S = 0·000,002,498 will be restored."

5. "The aggregate average discharge per second before the jetties were built will also be restored."

On these assertions the hydraulic radius between the jetties is computed to "be 42·22 feet at mean half-tide, or 39·71 feet at mean low-water."

6. "In the new channel between the jetty-heads, where the hydraulic radius is 39·71, it may be expected that the area of depths of more than 24 feet will constitute a very large proportion of the total area of the gap, and that maximum depths of 75 feet and upwards would be maintained in mid-channel."

7. "The sectional area of the gorge profile between Cumming's Point and Sullivan's Island is:— . . . Mean ebb-tide area 176,600 square feet."

From extracts Nos. 4 and 5 it would appear that there will result the same surface slope (S), and the same aggregate average discharge (Q) after the construction of the jetties as before. In other words, the jetties would not affect the slope or aggregate volume. In the Chezy formula for the velocity of discharge, which was used in this case, $V = C\sqrt{R\,S}$, and, solving with reference to S, it becomes $S = \frac{V^2}{C^2 R}$, but R is equal to the area (A) divided by the wetted perimeter (p), which latter may be regarded as a constant. Hence, if S is constant, or "remains the same as before," $\frac{V^2}{R}$ must be a constant ratio, or V^2 must vary as R varies; but R being a function of A, is reduced nearly one-half by construction, hence V^2 must also be reduced nearly one-half. As the quantity is a product of the area into the velocity, and as both of these factors are reduced by the construction of the jetties, it follows that the "aggregate average discharge" cannot be the same as before.

Moreover, since the jetties are about half constructed, a maximum depth between them might be expected of the half of 75 feet, or $37\frac{1}{2}$ feet, instead of 13, if the assertion in 4 and 5 be correct.

As a matter of fact, a contract was made for dredging between the jetties, for an amount not to exceed 200,000 cubic yards, at 30 cents per cubic yard. This contract was terminated on the 31st of December, 1885, after 85,549 cubic yards of material had been removed.

In the report of 1888, ten years later, it is stated that the jetties have been partially completed, so that the north one extends 14,327 feet seaward from Sullivan's Island, and the other 16,440 feet from Morris Island; total 30,767 feet, or nearly 6 miles.

The effects produced may be briefly stated in the language of the officer in charge:—"There has been a decline of about 25 per cent. in the rates of freight and insurance, and in marine insurance of 50 per cent. between 1878, when the jetties were begun, and the present; but these gratifying results cannot be ascribed to any improvement thus far made by the Government" (p. 974).

"The 12-foot curve has throughout made a marked seaward movement, and has preserved its form of former years remarkably. The outer 15-foot curve has been pushed seaward, so that the distance between the 15-foot water inside and outside of the bar is the same as last year. The outer slope of the bar is steeper than in 1887, and still more so than in former years. All these changes point to a general movement seaward of the material between the jetties, and a very considerable activity of the ebb-tide scour" (p. 973).

In fact, the results as shown by both the report and the chart show a decided progression of the bar without the desired lowering of the plane of tidal scour. The "thalweg" of the channel will be found to be reflected from the convex northern side of the south jetty, where spurs have been needed for protection, across the mouth or gap diagonally to the outer end of the north jetty, and having a least depth of only 10·4 feet. The least distance across the bar between the 12-foot curves within the jetties is 1,100 feet.

Under the most liberal construction, therefore, the Author fails to perceive wherein this experiment has proved beneficial.

In this connection, however, it would seem important to place upon record the unexpected improvement effected by the sinking of the "stone fleet" in the channel over the Charleston bar, with the intention of blockading the harbour during the Civil War. It serves to impress the importance of controlling the sand movements, and protecting the ebb currents in their path to the sea.

This phenomenal experience is described in a Paper by Professor Julius E. Hilgard, late Superintendent of the United States Coast and Geodetic Survey.[1]

Professor Hilgard says:—"On the accompanying diagram is seen the 'stone fleet' sunk in the main channel, which at that time had 12 feet of water at low tide, where the figure 7 indicates the present depth. There was, moreover, another channel, making out more to the southward, with 9 feet of water, where the figure 3 indicates the present depth. The vessels were placed checker-wise, in such a manner as to impede navigation, while interfering least with the discharge of water. The effect, nevertheless, was the formation of a shoal in a short time, and the scouring out of two channels, one on each side of the obstructions, through which 12 and 14 feet can now (January 27, 1871) be carried at low-water. The increased water-way thus given to the ebb-tide, caused it to abandon the old 9-foot channel on the less direct course to deep water. We have here the total obstruction of a channel which was of considerable importance to the southward trade, by new conditions introduced at a point 4 miles distant from where the effect was produced, and we are warned how carefully all the conditions of the hydraulic system of a harbour must be investigated before undertaking to make any change in its natural conditions, lest totally unlooked-for results be produced at points not taken into consideration."

So that, instead of obstructing the entrance, this accidental barrier to the flood actually deepened the water on the bar 2 feet, and induced the ebb-currents to effect an escape in its lee, closing a channel several miles to the westward by furnishing a line of less resistance, and withdrawing the water from the former distant channel. Moreover, it cut a second channel quite as deep as the first on the opposite side of the fleet, thus creating two channels as good as or better than before, instead of the one formerly existing on the site of the fleet.

This and other instances, where single jetties have been correctly located, go far to establish the soundness of the requirements to be observed in all constructions for improving the crossing of the outer bar, whenever it is the result of littoral drift.

These requirements briefly stated are:—

(1) To keep out the material carried up on the bar by the flood component.

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[1] Annual Report of the Board of Regents of the Smithsonian Institution, 1874, p. 221.

(2) To admit as large a portion of the tidal-prism as possible.

(3) To prevent the advance of the foreshore, resulting from the construction of solid jetties springing from the shore and forming groynes.

(4) To change the conditions of equilibrium of the flood and ebb currents over the same part of the bar in favour of the ebb.

(5) To prevent the dispersion of the ebb over a large sector of the outer bar, and to concentrate it along the line of least resistance.

(6) To construct a barrier of such form and position as not to generate injurious or destructive cross currents and eddies.

(7) To leave an ample waterway, and provide additional aids to navigation.

(8) To reduce the length of the breakwater, and consequently its cost, to a minimum, and yet furnish a safe roadstead and harbour entrance.

To meet these requirements, the Author has submitted a form of structure of a crescent or concave enceinte, and having a straight or slightly curved flank at its inner or shore end, which is intended to be placed upon the outer bar to seaward of the main channel, and to be raised to or above high-water.

By this exterior concavity it is expected that the wave action will be decomposed and tranquilized, while its burden of sand will be partially deposited in the cove thus formed, and tend to reinforce the outer slope of the work.

By leaving the beach channel open, and directing the inshore flank towards the gorge, the littoral movement of the flood will not be materially interrupted, and the foreshore will be prevented from advancing, the beach channel will be improved, while the ingress of the flood through this opening will exceed the egress of the ebb, thus throwing a larger volume at ebb over the main crossing of the bar.

Thus, by a single line of defensive works, it is expected to secure much more beneficial results at about one-half the cost.

A knowledge of the causes of the prevailing direction of the littoral drift enables the engineer to determine the proper position for those works. This subject was investigated by the Author in 1887, in a Paper entitled "The Physical Phenomena of Harbour Entrances," which was published in the Proceedings of the American Philosophical Society, Philadelphia, 1888.

In the discussion which followed, the general impressions appeared to be that there was no prevalent angle at which the breakers approached the shore, or if there were, it was mainly influenced by

the direction of the wind, and a standard authority in a work just issued states, that while on the open ocean the direction of the waves is the same as that of the wind, along shore they move normally to the beach. To show that these impressions do not accord with the facts, the Author made some instantaneous photographs of the breakers at Atlantic City, N.J., when the wind was blowing parallel to the crest of the waves, and during the second quarter of ebb-tide, which exhibit a very decided angle of approach, the direction of the movement being south-west, which accords with that of the inlets along this part of the coast.

The conclusion reached by the Author was, that the dynamic action of the breakers, especially during flood, being guided by a receding shore line, controlled the direction of the beach movement, and indicated the remedy for bar improvements.

A remarkable confirmation of the good effects secured by locating a single jetty upon the proper side of the channel, namely, that from whence the drift approaches, is to be found in the experience furnished at Aransas Pass on the coast of Texas.

Here, in 1869, a private company built a jetty only 600 feet in length, at a cost of $10,000. It was placed on the north side of the pass, and almost immediately resulted in an improvement of the channel, which was maintained until this temporary structure was destroyed by the waves and teredo several years thereafter.

(*Paper No. 2411.*)

"Compound Locomotives."[1]

By Ernest Polonceau, Chief Locomotive Engineer, Orleans Railway.

The results of experience show that stationary compound condensing engines and marine engines are economical; but it does not follow from that that the compound system is advantageous for locomotives. The duty of locomotives is very different from that of other engines, in that their work constantly varies. The compound system is particularly economical where the work to be done is constant, but not otherwise; and the system suitable for the one kind of engine is unsuitable for the other. For fair comparison reliance must be placed only upon trials made with locomotive engines of different systems, and under exactly similar conditions.

If an engine is modified by increasing its adhesive weight, which was previously very slight in regard to the heating surface, economical results will evidently follow the adoption of the compound system, which necessarily increases the adhesive weight, but these results prove nothing. New apparatus, when first tried and carefully attended to by its inventors or agents with a picked staff, always shows a considerable economy; but when left to the care of more or less capable ordinary attendants, it often does not give half the economy found on the trials.

The Author is convinced that there is an economy of fuel with the compound system; but, all other things being equal, he does not think it can exceed 5 to 8 per cent.; now, between a good and an average engine-driver the differences far exceed 5 to 8 per cent., reaching even 50 per cent. with a mean of 15 to 20 per cent. In the same way, between a locomotive having its working parts and tires in perfect order, and another on the point of return to the shops after prolonged service, there is a difference of consumption, which often reaches 15 to 20 per cent.; comparing the cost of fuel per 100 kilometric tons gross, there was for the entire network of the Orleans Company in 1887, 5·86; in 1888, 5·76; or a difference of 2 per cent.

If the premiums obtained by engine-drivers be taken into con-

[1] This communication was intended for the Correspondence on Mr. E. Worthington's Paper, vol. xcvi., p. 2, but was not received until that article had gone to press.—Sec. Inst. C.E.

sideration for fuel, oil, time saved, overloading, &c., the following differences will be found:—

—	Express.	Passenger.	Merchandise.
	Per cent.	Per cent.	Per cent.
Depot at Paris	38·93	59·07	75·75
„ Orleans	38·52	66·79	69·65
„ Tours	67·54	83·52	88·00
„ Perigueux	80·07	41·65	50·00

Among the advantages claimed for the compound system are:—

1. Facility in starting. The Author believes, however, that the contrary may be said in many cases. Nevertheless, French locomotives have valve-gears of such design that they readily start their trains, and very soon attain full speed. The inconvenience of sluggishness in starting met with in certain types of locomotives, can be avoided; it is a question of gear.

2. The exhaust-pressure being diminished, it results therefrom that sparks are not thrown out. But the same results may be obtained by adopting variable exhaust, which is not uncommon in France, and by giving in every case sufficient section to the blast-pipes. Trials have been made on the Orleans Railway with the fixed exhaust of Mr. Wassner, which seem to give good results: the exhaust is into a hollow ring provided with a series of small taps placed round it. The blast, under these conditions, is more regular, and it seems to facilitate the employment of slack coal; it does not make the fuel scatter in the furnace. A good result also follows with the Lencauchez system, which reconveys to the boiler a portion of the exhaust steam, and diminishes the quantity discharged into the atmosphere, thus promoting also economy of fuel. Some goods locomotives on the Paris and Orleans Railway are provided with the Lencauchez apparatus, whereby an economy of 5 per cent., perhaps more, is gained; for passenger locomotives this system has been given up because of its complexity.

3. Compound engines are more steady. So far compound engines have outside cylinders, or outside cylinders and one or two inside cylinders; now engines with outside cylinders will always be less steady than those with inside cylinders. The Author has had in use, and still employs engines on the two systems, and there are such considerable advantages in having inside cylinders that, except under special circumstances, he finds it preferable to use

them. They are at least as steady as any form of compound engine.

4. The compound engine diminishes the difficulties due to the wire-drawing of the steam.

In ordinary locomotives, wire-drawing induces the superheating of the steam, which occasions the seizing of the friction surfaces of the slide-valve and of the piston. This inconvenience can be remedied by lubrication, if need be, from the foot-plate when running, and also by slightly opening the water-cock of the Le Chatelier apparatus. The advantage of the compound engine in this respect does not give it any absolute value; there remains the fall of pressure from the wire-drawing of the steam; but its importance does not seem to be very great, and may be overcome by special arrangements.

5. The compound engine diminishes condensation and re-evaporation.

To compare the influence of condensation in compound engines with that in engines with single cylinders, the result is all in favour of compound engines; but it has been observed that the steam moves so rapidly in the cylinder of locomotives that this is less noticeable than in engines where the speed is less. Steam at the initial temperature coming in contact with the cylinder at the exhaust would encounter theoretically a surface at a temperature of 212° Fahrenheit, and would be rapidly condensed while raising the temperature of the cylinder, which in its turn would produce an evaporation of the water during expansion, which is useful, and evaporation during exhaust, which is a loss. Another phenomenon must then intervene, particularly in locomotives, namely, the thermic influence of compression. There succeeds then a series of phenomena in a space of time which is worthy of notice. At high velocities locomotive driving-wheels attain a speed of four or five revolutions a second, or eight or ten cylinder strokes. The series of phenomena under consideration ought then to be developed in one-eighth or one-tenth of a second. It follows that practically the cylinder of a locomotive takes a mean temperature, the variations from which are very slight, and that the results of condensation are very different from those which are produced in a low-speed stationary engine. The compound engine, besides, fully makes up for these considerations by the dimensions of the large low-pressure cylinders, which in Mr. Webb's "Dreadnought" attain 23½ to 26 inches in diameter, and which consequently present a considerable cooling-surface. Very great condensation results therefrom, which is disadvantageous.

But it does not therefore follow that compound engines should be abandoned. When in Austria, the Author constructed a compound locomotive on the Webb system for the Austro-Hungarian State Railways; and had not many of his colleagues done so too, he would have been one of the first to have made experiments with it, but under present circumstances he awaits the results of trials on a large scale made in various quarters.

The compound engine is the solution of a difficulty felt in countries where fuel is very dear, and under special circumstances; but Watt has said: "In all things, and especially in mechanics, it is necessary to seek simplicity," and compounding is a complication in the locomotive. High pressures cannot be actually used in locomotives, because of the character of the valve-gear, which is not adapted for prolonged expansion. With the compound system the latter can be prolonged further. In the express engines of the Paris and Orleans Railway, adapted to a pressure of 142 lbs. per square inch, the exhaust commences at 52 per cent. of the stroke, and the steam escapes at 42 lbs. If the pressure is much higher than 142 lbs., steam will be exhausted at 70 or 85 lbs. per square inch, which would hardly be economical. At speeds of 47 to 50 miles an hour, this exhaust or 52 per cent. of the stroke is less inconvenient, for it has been proved by diagrams that the steam has not time to escape fast enough; the fall of pressure is not rapid, as in engines of low speed, and the effective expansion is greater than the normal expansion. The compound locomotive would then certainly be theoretically an economical solution; but it would be necessary, as in stationary or marine engines, to be able to give the cylinders the dimensions desired. But, between the sole-bars there is insufficient room, and moreover, space is wanting on account of the gauge. Practically, the Author does not believe that the economy realized makes up for the difficulties of maintenance arising from mechanical complication, and the supplementary expenses of lubrication, even for two-cylinder compound engines; for, despite all precautions, the work is unequal on each side of the engine, and the result is evidently loss of power, and dislocations more or less rapid and injurious. The double-expansion compound locomotive is thus not economical. Recourse must therefore be had to the three- or four-cylinder compound engine; but in this case, in the Author's opinion, the economy in fuel will be almost counterbalanced by the increase of expenditure of construction, of lubrication, and of maintenance of the machinery. Finally, he may cite the conclusion submitted to the Thirteenth Congress of the Chief

Engineers of the Steam-Users Association, held in Paris on the 11th, 12th, and 13th of November, 1888, by Messrs. Coste and Bour:—

1. The compound system applied to locomotives has little elasticity, and the normal performance of an engine designed for special conditions of work may become very defective as soon as these conditions are departed from.

2. The compound engine is less adapted to regular work than a single-cylinder engine, when both are applied to variable work.

3. The compound system does not lend itself easily to the performance of dual functions, in the sense that the conditions of work of a condensing engine will differ from those of a non-condensing one. Thus if, in a particular engine, any departure is made from a certain average performance, one or other of such performances is likely to be very defective.

4. Non-condensing compound engines present, in an exaggerated degree, all the defects found in condensing compound engines.

5. The compound engine can hardly be considered an industrial motor, susceptible of being established according to fixed types capable of meeting the general requirements of workshops. Good in certain cases, in others it may give rise to serious disappointment, unless special precautions have been observed. There are, moreover, cases where it ought never to be adopted. The single-cylinder engine, on the contrary, admits of types being established of more general use.

Point 2 applies in a special manner to locomotive engines; and the general result of these conclusions entirely confirms the Author's opinion on the application of the compound principle to locomotives.

(*Paper No. 2416.*)

"The Bore of the Tsien-tang-Kiang."

By W. USBORNE MOORE, Commander R.N.

AMONG the periodical phenomena of Nature, none are more deserving of attention than the tides; and of the various phases of the tides, none are more worthy of study than the phenomenon of the bore. To Civil Engineers, especially those engaged in works on the sea-coast, it will probably have a peculiar interest, as it presents a marked instance of wasted power. Possibly, the day is not far distant when the energy exerted by the tides generally, and by this crowning development in particular, may be brought under control in practical affairs.

The bore,[1] called also the "Hygre" and "Eagre" in England, "Mascaret" in France, and "Pororóca" or "Prororóca" in Brazil, is well known in six or eight rivers in the British Islands, in two or three of those in France, in some of the Indian rivers, in the branches which compose the mouth of the Amazon, and in one river at least in China. It is rarely observed except at spring-tides, and, as a rule, shows itself on the days of full and of new moon, appearing with the first of every flood for three or four days succeeding those phases, after which the tide comes in with only a swift rush without noise or violent commotion.

The conditions necessary for its creation appear to be three:—(1) A swiftly flowing river; (2) An extensive bar of sand, dry at low-water, except in certain narrow channels kept open by the out-going stream; (3) The estuary into which the river discharges must be funnel-shaped with wide mouth, open to receive the tidal-wave from the ocean.

When either of these conditions is absent, the bore is not known. Thus, in the Thames, although the third condition is present, the first and second conditions are absent; for the stream is not swift, and there is no bar dry at low-water. In the Severn, all three conditions are present, and there is a bore, not a very large one, but the highest in these islands.

[1] Derived probably from the Icelandic "báva," a "billow"; "eagre," from the French "eau-guerre," or "water-war.

The bore of the Tsien-tang-Kiang,[1] in China, has the three conditions developed. The estuary into which the river falls has a vast area of sand at its head, and is favourably situated for the reception of the tidal-wave from the Pacific, which approaches the coast from the east or east-south-east. The range of the tide immediately outside the Hang-chau gulf is 12 feet; but as the wave becomes compressed on advancing towards its head, at the end of the navigable waters, it is as much as 25 feet at ordinary spring-tide, and 34 feet when the wind is blowing on shore and the moon in perigee at the time of full and change. The navigable breadth of the estuary, at its head, where the tidal-wave rises to its greatest height, is about one-fifth or one-sixth what it is at the mouth; and if there were no river discharging into the bay, the range would probably be between 60 and 70 feet, as it is in the Bay of Fundy.

For the first hour the tide rises 10 to 12 feet, and the pressure is then relieved by the overflow over the bar into the river. In crossing the bar, first of course through the narrow river channels, the flood meets with the swift outgoing stream, which trips up its foot and causes an overfall; then, as more rushes of water overlie the first of the flood, the inequality of level becomes greater until the water rises to a bore, which advances with increasing velocity, but great regularity of front, towards the mouth of the Tsien-tang. So far as is known, there are only two branches of the bore over the sand flats. These join 4 miles outside the mouth of the river, and here the flood again becomes compressed between the banks. At low-water the river is only 1 mile broad, and there is a great rise in the height of the approaching cascade after the junction of the two rollers.

While the flood is travelling across the sands, the water is rising steadily at the end of the navigable portion of the Hang-chau gulf; and, by the time the two branches of the bore join, there is a difference of level of 19 feet at springs between the water on the outside of the bar and that in the mouth of the river, a distance in a direct line of about 20 miles. Accordingly, the flood enters the river down a gradient of 1 foot in a mile with great force, and is assisted by the transmitted pressure of the advancing tidal-wave in the estuary. The speed, as measured by the officers of H.M.S. "Rambler," is 12·7 knots, or 14·6 statute miles, an hour. The bore has a breadth of 9 cables, or 1,800 yards, and its front is a gleaming white cascade of bubbling foam 8 to 12 feet high, pound-

[1] A more detailed account of the bore of the Tsien-tang-Kiang, by the Author, of which a copy is in the Library, has been given in Vol. xxiii. (1888), of the Journal of the China Branch of the Royal Asiatic Society.

ing on itself and the river in front of it at an angle of from 40° to 70°, the steepest and highest portion being over the deepest part of the river, where the outgoing stream has the greatest velocity.

The noise is not the least impressive feature of this phenomenon. On a calm, still night it can be distinctly heard, when 14 or 15 miles distant, an hour and twenty minutes before arriving. The noise increases very gradually, until it passes the observer on the bank of the river with a roar but little inferior to that of the rapids below Niagara.

The bore maintains its breadth, height, speed, and regular appearance, for 12 or 15 miles above the mouth of the Tsien-tang. As the bed of the river slopes gradually up from Haining, near the mouth, to the city of Hang-chau, which is 24 miles from the mouth, the range of tide gradually decreases from 19½ feet to 6 feet; and the bore passes Hang-chau at a much reduced height, seldom exceeding 5 feet even under exceptional circumstances. It usually then breaks up. On certain rare occasions, however, after a full or a new moon in perigee, and when the opposing river is stronger than usual owing to heavy rains in the interior, it proceeds up-stream beyond the city for 30 miles, before losing its distinctive character.

The peninsula situated between the Yang-tze-Kiang and the Tsien-tang-Kiang is a flat, densely populated, and richly cultivated district, formed by the alluvial deposit from the former river. It is intersected with canals, which admit of journeys being made with great facility between Shanghai, Haining, the city of Hang-chau, and the numerous towns, some of which are of considerable size, between these places. If it were not for some protection, this peninsula would be flooded by the spring-tides, for the general level along the north side of the Hang-chau estuary and the Tsien-tang is some 2 to 6 feet lower than high-water of ordinary spring-tide, and it is believed to be still lower at Shanghai. To protect this country from the ravages of the sea, a substantial embankment has been thrown up from the mouth of the Wu-sung river, round Yang-tze Cape to beyond Hang-chau, a distance of 120 miles. This of itself is not a sufficient barrier at that portion of the estuary and river where the bore is known, and it has been flanked for about 30 miles by a sea-wall between 30 and 40 feet thick, which is certainly a most creditable public work. It has been built eight or nine hundred years. The top varies in elevation from 3 to 9 feet above high-water of spring-tides. It is faced with blocks of stone 5 feet long, 16 inches broad, and 14 inches deep, laid at right-angles to the river, and joined together by rivets of

iron. At numerous places by the side, especially within the river, platforms have been constructed of large blocks of stone enclosed by piles, to enable the junks to ground in safety from the violence of the bore. One of these platforms at Haining is 1,100 yards long, 20 feet wide, and 7 to 8 feet above low-water of ordinary spring-tides, which reaches horizontally to within 5 or 6 feet of the foot of the piles confining the stones on the shelter. At the east end of the platform there is a semi-elliptical buttress, 253 feet long and 66 feet wide, parallel to the sea-wall, built of mud, surrounded by fascines: and there is a similar buttress at the west end. The junk platform is well inside a direct line between the tangent of one buttress and that of the other.

At the platforms the sea-wall is ascended by a succession of steps about 4 inches in width, which are sufficient to give a footing, but not sufficiently broad to permit the flat bottom of a junk catching upon them as it is hove up and down by an agitated flood.

The northern edge of the bore advances along the wall, and, when it meets with the buttress, is deflected into the middle of the river. The full force of the cascade is, therefore, not felt at the platforms. When the junk-master sees or hears the bore approaching, he summons his crew, looks to his warps, and stands by to fend off his vessel from the wall. After the passage of the bore, and of the agitated water which follows it for about a mile, the junk is afloat in comparatively still water, and the junk-master completes his loading and proceeds on his voyage.

Great skill is exhibited in the construction of the shelters. They are of different heights, some only being intended for use in the winter, when high bores are expected; never so high but what a junk floats directly it is safe for her to do so, nor so low but that she can obtain adequate protection from the force of the bore; assuming, of course, that the master does not neglect the usual warnings, and takes care to ground his junk at a high-level shelter when an unusually high cascade is anticipated. In the river there is no place where even the shallowest junks can be secured in safety from the bore two and a half hours after the water has begun to fall. Navigation for ships is out of the question; for boats, it begins directly the after-wash behind the bore has passed by, and ends two hours after high-water, a period of from three to four hours, according to the distance from the mouth of the river.

The natives at Haining state that the bore is the necessary accompaniment of the first of every flood-tide throughout the year. At 15 miles above Haining the phenomenon does not appear at neap-tides, and it is not dangerous at neaps to well-managed boats

even at Haining. Two days before new moon of December 1888, a junk was seen to ride over it at anchor. It is not safe to attempt this, even in the finest weather, between the day before and five days after, full moon and new moon. The Author saw a bore off Haining pagoda two days after new moon, in October 1888, which, in his opinion, would have sunk any vessel of 300 tons at anchor in the stream.

As a rule, two-thirds of the flood-range of tide arrives at Haining within fifteen minutes, and the top of the bore, that is, the cascade in front of the flood, is as high as the mean level. The highest recorded is about 15 feet.

Occasionally, the two branches of the bore meet with exactness, the right extreme of the one line of breakers with the left extreme of the other; and the combined roller, 2 miles broad, presents an imposing appearance as it advances towards Haining. When about 2 miles east of Haining, the flood-stream runs with great violence into the sea-wall. It appears as if the south-east branch of the flood has acquired too much impetus to adapt itself immediately to the new direction, and runs over or through the northern branch which skirts the sea-wall. The result is a rebound which raises a series of high waves, the tops of which are, for several minutes, higher than the level of high-tide; the water in the estuary being violently agitated for 1½ mile or 2 miles; and the waves, taking a south-westerly direction, break, and by degrees subside on to the back of the bore. The sea-wall has an additional outwork of piles and stones where the flood impinges.

On entering the river, the flood has a concave transverse surface, and complete lateral equilibrium is not restored until nearly high-water.

The following Table shows the readings of the tide-poles at Haining, Rambler Island (near the western end of the navigable portion of the Hang-chau gulf), West Volcano Island, and Changtau harbour, for one tide. *Fig. 1* explains graphically these simultaneous observations of the height of the water at four stations between 8 P.M. on the 20th and 9 A.M. on the 21st of September 1888. At full and at new moon, it is high-water at Changtau at 10 hours 14 minutes; West Volcano Island 0 hour 19 minutes; Rambler Island 1 hour 27 minutes; Haining 3 hours; and Hang-chau 3 hours. The bore forms 12 to 16 miles east of Haining about 10 hours 30 minutes, passes Haining at the rate of 21 feet a second, precisely as the moon crosses the meridian of that place, or 12 hours 20 minutes after the passage of the moon to which the origin of the phenomenon is due, and reaches Hang-chau about 2 hours. At Changtau and West Volcano Island, the flood lasts

SIMULTANEOUS OBSERVATIONS of the DISTANCE of the WATER from MEAN LEVEL at HAINING, RAMBLER ISLAND, WEST VOLCANO ISLAND, and CHANGTAU HARBOUR, FULL MOON, SEPTEMBER 1888.

The Flood.

20th September.

Hour P.M.	Above or Below the Mean Level.			
	Haining.	Rambler I.	W. Volcano Island.	Changtau.
H. M.	Feet Ins.	Feet Ins.	Feet Ins.	Feet Ins.
8 30	..	−11 4	− 1 1	+ 3 7
9 0	..	−10 9	+ 0 4	+ 4 5
9 30	− 8 0	− 9 6	+ 1 6	+ 4 10
10 0	− 9 0	− 4 3	+ 2 7	+ 5 4
10 30	− 9 0	+ 1 3	+ 3 6	+ 5 5
11 0	− 9 6	+ 5 9	+ 4 4	+ 5 2
11 30	− 9 6	+ 8 3	+ 4 11	+ 4 8
Midnight	− 9 9	+ 9 6	+ 5 6	+ 4 1
21st September.				
0 20	Bore passed Haining.			
0 30	+ 3 0	+10 4	+ 5 7	+ 3 4
1 0	+ 6 0	+11 3	+ 5 2	+ 2 1
1 30	+ 8 0	+11 7	+ 4 6	+ 1 2
2 0	+ 9 0	+11 5	+ 3 7	+ 0 3
2 30	+ 9 6	+10 11	+ 2 5	− 1 2
3 0	+10 0	+ 9 10	+ 1 4	− 2 7

The Ebb.

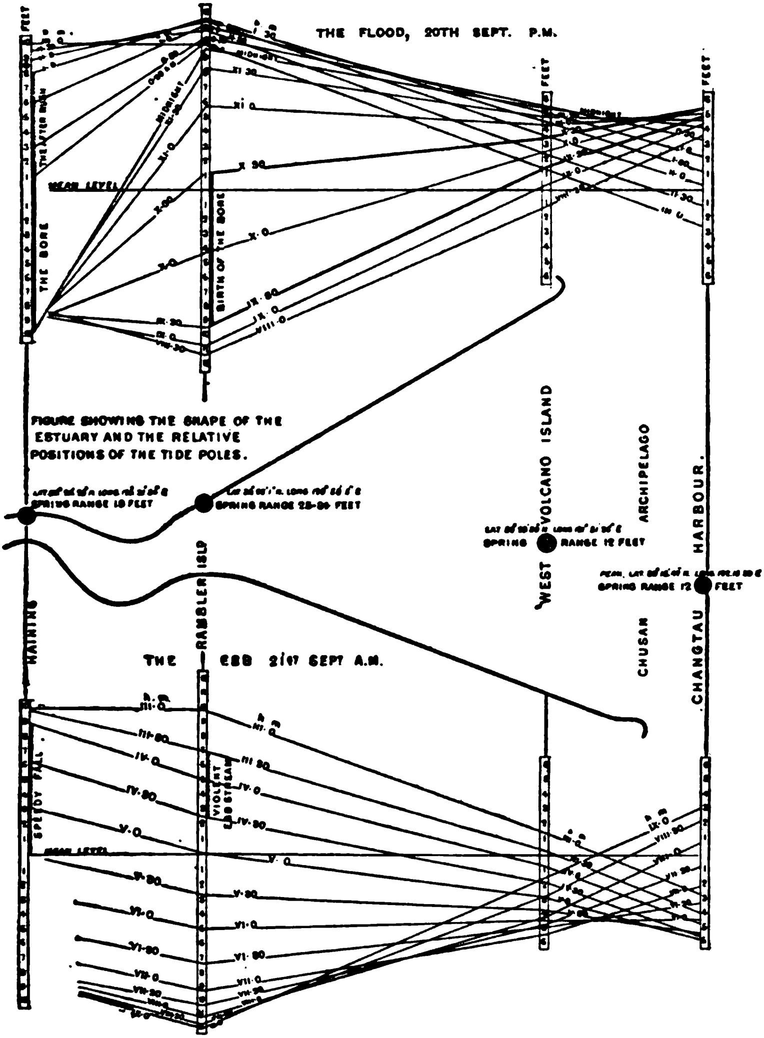
21st September.

H. M.	Feet Ins.	Feet Ins.	Feet Ins.	Feet Ins.
3 0	+10 0	+ 9 10	+ 1 4	− 2 7
3 30	+10 0	+ 7 0	+ 0 3	− 3 10
4 0	+ 9 0	+ 5 0	− 0 9	− 4 8
4 30	..	+ 2 6	− 1 10	− 5 7
5 0	..	+ 0 1	− 2 10	− 5 9
5 30	0 0	− 2 7	− 3 9	− 5 4
6 0	..	− 5 0	− 4 6	− 4 6
6 30	..	− 7 5	− 5 0	− 3 4
7 0	..	− 9 3	− 5 6	− 2 2
7 30	..	−10 5	− 4 11	− 0 10
8 0	..	−11 3	− 4 5	+ 0 7
8 30	..	−11 9.	− 2 10	+ 2 2
9 0	..	−12 0	− 1 8	+ 3 0

for six hours, the ebb for six hours; at Rambler Island, the flood lasts for five hours, the ebb for seven hours; at Haining the flood for three and the ebb for nine hours; and at Hang-chau the flood lasts for about an hour and a quarter, and is nearly all in the bore. The stream commences to run out of the river along the right

or south shore an hour before high-water at Haining, though the tide continues to rise on the bank, a peculiarity which has yet to be explained; and in the middle of the stream it turns directly it

Fig. 1.



has ceased to rise at the shore. A review of the simultaneous levels shows that, at this time, the water at Rambler Island near the end of the navigable portion of the Hang-chau gulf, after

rising to its highest for that tide, has fallen just below the level of high-water at Haining; and as the estuary at Rambler Island is about four times as broad as the river at Haining, directly the water falls in the former, that in the latter must promptly obey the movement. In about five hours, the water in the river has fallen to within a foot or 18 inches of its lowest for that tide; the last foot dribbles away very slowly, and for two hours previous to the arrival of the new bore, it only falls 4 or 5 inches. The stream of the river, however, continues to make out fast along the channel, and is found opposing the incoming flood.

The readings at Haining and Changtau can only be regarded as approximate; but they are correct within 6 inches. It will be seen that the sudden rise of tide at the head of the Hang-chau estuary (Rambler Island) between 9 hours 30 minutes and 10 hours 30 minutes P.M. on the 20th of September, 1888, was the birth of the bore. The force which propels this body of water with so much violence over the bar is indicated by the difference of level of the water between Changtau and Rambler Island, which at 9 hours 30 minutes is 15 feet, and at 10 hours 30 minutes 4 feet 2 inches.

Information concerning the phenomenon in any part of the world is exceedingly meagre.

As the bore is, in all cases, the result of difference of level between the ocean and the river, it is necessary to establish tide-poles, and watch the movements of the tidal-wave at four or five points simultaneously; but this operation is seldom possible except with the resources of a surveying ship.

The time may come when the enormous power concentrated in this impetuous descent of the flood shall no longer be wasted, but be utilized, either in the storage of electricity, the compression of air, or in the working of machinery; and, instead of, as at present, being regarded as a fine spectacle at the best, and always a curse and hindrance to industry, the phenomenon, which is the subject of these remarks, may be turned to a sound practical use and benefit to humanity.

The Paper is accompanied by three illustrations from which the *Fig.* in the text has been prepared.

(*Paper No. 2442.*)

"Scientific Fortification in China."

By WILLIAM MACDONNELL MITCHELL DOWDALL, Assoc. M. Inst. C.E.

OWING to the sudden illness and return home, before work was commenced, of the officer[1] sent out specially from England to design and construct the first batteries in China, upon foreign principles mounting heavy (40-ton) guns, the Author was called upon to quit his civil pursuits and give the Chinese on the Yang-Tsze-Kiang their first insight into the art of scientific fortification.

Although the enterprise followed close upon, and was the immediate result of, the so-called war between France and China in 1885, it partook rather of the nature of an experiment, as the Chinese, having experienced the superiority of foreign ships and artillery, were anxious to institute a comparison between native and foreign land batteries.

Native fortifications consist generally of either a high brickwork rampart with square bastions at intervals, surmounted by a weak parapet with embrasures and loopholes; or simply a high mud rampart with practicable slopes on both sides, bastions and parapet as before, but all in mudwork. The ditch would not appear to be any part of the system, nor has flanking apparently been thought of, the bastion being merely a device to get nearer to the enemy; and as to "enfilade," "defilade," "glacis," "oblique," "reverse," or any of the hundred scientific terms familiar to every novice in the art, their meaning is unknown. Little need be said of the armaments, which in the majority of cases consist of rusty old smooth-bores, often with wrought trunnions strapped on with a band, to replace those knocked off by the foreign "barbarians" during some of their former descents upon the shores. Occasionally an Armstrong gun may be met with in a shed, with hydraulic gear, out of order, a discarded Moncreiff mounting, or some such innovation. Hence, although the work in hand presented few engineering difficulties, it bristled with obstacles from beginning to end, placed in the way by ignorance, prejudice, and peculation; and which were overcome only by patience, persistence, strategy, or open warfare. It is true there were associated with the work

[1] It cannot be traced that any officer of the British army has been sent out from England for this duty.—SEC. INST. C.E.

several Chinese gentlemen of enlightenment and intelligence; but unfortunately they lacked sometimes the power, and sometimes the will, to make matters smooth.

The sites chosen for batteries, or "forts," generally had one of two distinct characteristics; they were either low marsh ground, little raised above the sea-level, or high precipitous hills of almost bare rock.

Near Woosung, in the embouchure of the Yang-Tsze-Kiang, at the entrance to the Hwang-Poo or Shanghai River, and about 15 miles from the latter port, an extensive battery upon the low marshy ground was planned.

The guns were delivered at one of the docks at Shanghai, and there, by means of shears and capstan, safely embarked on board a 100-ton barge specially constructed, and thus towed to their destination. Here the appliances of civilization were left behind; for, with the exception of some hydraulic jacks, and crabs, thoughtfully sent out from England with the guns, there was no appliance capable of lifting the guns, and no man who had cast eyes upon such monsters before.

The design for the emplacements having been settled, drawings had to be prepared of concrete-boards, watering-pots, and even shovels, the "braves" of the garrison, upon whom devolved the bulk of the work, being totally unacquainted with them. Next, the workmen had to be instructed in the art of mixing concrete—no easy task for a single individual possessed of little previous experience in the handling of a shovel, where the pupils were numbered by thousands, for each camp or battalion had its own gun, and the men once taught at one gun could not be made use of at the next; and where the thermometer ranges for months between 90° and 100°, and sometimes exceeds the latter point. Next, a foundation of about 1 to 6 Portland cement concrete was laid 100 feet, by 40 feet, by 7 feet thick, on the surface of the low ground, in which were buried the massive holding-down plates and bolts; and here the whole surface of the ground was first riddled with small piles, like 16-foot scaffold-poles, and holes, 50 feet in diameter and 6 feet deep, were dug under the centre of each mounting and filled with large stones and whitewash.

Upon the concrete foundation the mountings, parapet, shell-proof expense magazine, shell-room, and loading gallery were buil also entirely of concrete. Finally, the pivot block of 6 tons, the slide of 6 tons, the carriage of $4\frac{3}{4}$ tons, and gun of 43 tons were in succession raised into position.

The guns are central pivoted, 12-inch, muzzle-loading, rifled,

axial-firing, Armstrongs, 25 feet in length, with rear racer, fired *en barbette*, over a 6-foot parapet, and loaded from a shell-proof gallery on the right of the gun, and fitted with hydraulic recoil cylinders and automatic carriage.

The second class of site was presented at Kiang Yin, about 80 miles further up the Yang-Tsze than Woosung, where two separate batteries were planned upon the hills, upwards of 100 feet above high-water level. In addition to the difficulties anticipated, and therefore half overcome, a new and formidable one here presented itself. It was argued that as the plan of an enormous bed of concrete and raised *terre plein*, adopted on the marsh at Woosung after much discussion, had there proved successful and satisfactory, the same system should be strictly adhered to on the rocky hill-tops. The obstinacy of the authorities upon this point was near causing the engineer to resign his post; but fortunately it was at last agreed to sink the whole emplacement in the solid rock, the only concrete used being the necessary packings of foundations, and linings of chambers, and the shell-proof vaults.

The patience, industry, and, in many cases, the intelligence of the "braves" (or regular soldiers, as distinguished from a militia of which the old standing army consists), were as admirable as the stupidity and obstinacy of some of the chiefs were annoying. The guns were landed from the barge, and parbuckled for miles up and down hill, upon gradients occasionally steeper than 1 in 6, and to the tops of the hills, by these hardy warriors with scarcely an accident or mishap.

The Chief Engineer of the "Yang Woo," the frigate destroyed by the French at Foochow, made a very efficient Resident Engineer, and the whole of the mountings and machinery, which were admirable specimens of workmanship from Messrs. Sir W. G. Armstrong, Mitchell and Co.'s works, were excellently put together by Chinese artificers from the Shanghai arsenal, who were constantly loud in their praises of the perfection of the work.

(*Paper No. 2405.*)

"The Tacheometer: its Theory and Practice."

By NEIL KENNEDY, M. Inst. C.E.

THE use of the tacheometer is common on the continent of Europe; and amongst Italian, French and Spanish engineers it is supplanting every other means of making the preliminary surveys connected with public works. In Great Britain, the ordnance maps eliminate a great deal of what otherwise would be its utility; but those English engineers who may have to work in new countries may find it advantageous to employ this simple method of preparing topographical plans in an expeditious and reliable manner.

The tacheometer is simply a transit theodolite, whose telescope is fitted with an effective distance-measuring arrangement, represented graphically in Plate 5, Fig. 1. Two horizontal hairs *a* and *b*, are placed in the diaphragm at equal distances from the central line of vision. A converging lens Q is also introduced between the object glass O and the diaphragm, so that the focal distances Q E and O F of the lenses, Q and O, overlap one another slightly; and F, the principal inside focus of the object-glass O, coincides with the vertical axis of the instrument. Rays parallel to the central line of vision, and passing through *a* and *b*, after traversing the focus E of the lens Q, pass on to *m* and *n* respectively, and leave the lens O in line with its principal interior focus F, along *m* A and *n* B. An angle, B F A, is thus formed, having its apex F in the vertical axis of the instrument, and is called the "measuring angle." So long as O is stationary relatively to Q, the measuring angle, B F A, is constant. By placing *a* and *b* at other vertical points, equally distant from the central line of vision, any other measuring angle can be formed without altering the apex F. This ingenious arrangement has been the chief means of bringing telescopic measurements within the field of practical surveying.

The introduction of extra horizontal wires in the telescope, as ordinarily supplied to theodolites, will not attain the same object (Plate 5, Fig. 2). The object-glass of the telescope is O, and *a* and *b* are the horizontal hairs introduced, the vertical axis of the

instrument lying between its object-glass and the hairs. All rays of light parallel to the central line of vision pass through the principal focus, F, of the object-glass O; therefore the ray passing through *a* will be converged at it, and pass on to A; and the ray through *b* will pass on to B. So long as *a* and *b* remain stationary in a vertical position, the angle B F A (Plate 5, Fig. 2) will be constant; but unfortunately, its apex, F, is at a distance, K, from the vertical axis of the instrument, which would have to be added to every operation.

A tacheometer recently constructed by Messrs. Troughton and Simms is shown in Plate 5, Fig. 3. One bubble is attached to the horizontal plate, and another, C, is connected to the vernier arms of the vertical circle. The clamping and tangent screws of the horizontal plate work in connection with a spring, which occupies the site where the compass is usually placed. The compass, E E, is detachable. The screw B adjusts the vertical circle, the zero diameter of which is vertical. This screw is turned by a key which is only fitted to it for adjustment. A similar detachable key fits in at A, and actuates the arrangement for adjusting the measuring angle. The hairs in the diaphragm are represented in Plate 5, Fig. 4. Those marked *a a'* produce a measuring angle, twice the tangent of the half of which is 0·02; and those marked *b b'* produce another angle, twice the tangent of the half of which is 0·004. These numbers are called the constants of the instrument. The eye-piece can be moved up and down by the pinion D, so as to obtain a clearer sight of the extreme wires. The vertical and horizontal circles of the tacheometer are usually divided into centesimal degrees of 100 to a right-angle, or 400 to a circle. By this system, speed and freedom from error are obtained when operating in the field; and, for office work, it favours the adoption of the slide-rule for the calculations. This latter seems to be the chief reason for this division, which, although peculiar, is very convenient. If those who first perfected the tacheometer had at once compiled tables on the principle of those which now exist, instead of using a slide-rule, it is possible that the centesimal degree would never have been adopted; and whenever full tables for ordinary degrees are formed, centesimal degrees will doubtless be abandoned. As a tacheometer divided into ordinary degrees serves all the uses of a theodolite, it is highly probable that, in the future, both instruments will be combined in one.

Adjustments of the Tacheometer.

The following are the permanent adjustments of the tacheometer, and it is advisable to execute them in the order given. Nos. 1, 2, and 3, being the same as in the theodolite, are not dwelt upon. Although No. 4 is also common, yet it is such an important one that it is explained at length.

1st. To place the plane, represented by the level attached to the horizontal plate, perpendicular to the vertical axis.

2nd. To place the central line of vision of the telescope perpendicular to its rotating axis.

3rd. To place the rotating axis of the telescope truly level.

4th. To make the zero line of the vertical vernier coincide with the horizontal diameter of the vertical circle, when the central line of vision of the telescope is truly level. This is a most important adjustment, and ought to be looked to at frequent intervals. On a fairly level piece of ground, fix two pegs as far distant as the telescope can conveniently read, and determine the exact difference of level between them by any known method. Place the tacheometer at one peg, in such a manner that the height of the telescopic axis above it can be measured; then level up the instrument, and make what ought to be the horizontal diameter of the vertical circle agree with the zero of its vernier. The horizontal diameter corresponds with 100° to 300° if the degrees are centesimal, or 90° to 270° if they are of the ordinary graduation. Clamp the circle and telescope thus, and direct it towards a staff placed on the other peg. The difference between the reading then observed and the height of the telescopic axis above the peg at which the instrument is placed, ought to give the difference of level previously found between the pegs. If it does not, turn round the telescope, the vertical circle, and its vernier, by means of the screw B (Plate 5, Fig. 3), until the central hair indicates the true difference of level. The adjustment is then complete.

5th. To correct the levels attached to the telescope and the vernier arm of the vertical circle. After the previous correction has been carried out, the bubble of the level, C, and that of the telescope ought to be in the centres of their runs; if not, then bring them to those centres by means of their suspending screws.

6th. To adjust the measuring angle. On fairly level ground, measure off with accuracy a line of moderate length, say 150 yards, and place pegs at its extremities. Over one peg place the tacheometer, and on the other a staff divided in the manner subsequently described. When the instrument is levelled up, direct the tele-

scope, when exactly horizontal, to the staff. The number of divisions between the upper and the lower cross-hairs ought to indicate the distance as measured from peg to peg. If this distance is not exactly indicated, turn the key, which fits in at A (Plate 5, Fig. 3), until the number of divisions between the extreme hairs indicates it.

The Staff.

The staff used in connection with the tacheometer ought to be about 14 feet long, broad enough to allow of marking it with clear bold figures, and its face ought to be in one plane. Above all it ought to be light. The manner of dividing it will be explained hereafter. When the metre is used as a unit of measurement, the size of a division is 2 centimetres. As the requirements of English practice oblige levels to be expressed in feet, it is possible that the most useful division for English work would be 0·02 of 10 feet or 2·4 inches. This could be subdivided according to the ideas of clearness possessed by the operator.

The Measurements of Heights and Distances by means of the Tacheometer and Staff.

Suppose B A C (Plate 5, Fig. 5) to be the measuring angle of a tacheometer whose apex is at A, and whose containing lines strike, at B and C, a graduated staff held at right-angles to A D, the central line of vision. B C is equally divided in D; and A D represents the distance between the staff and the apex of the angle, or the axis of the instrument. Then $A\,D = \frac{B\,D}{\tan B\,A\,D}$, but $B\,D = \frac{B\,C}{2}$, and the angle $B\,A\,D = \frac{B\,A\,C}{2}$; therefore,

$$A\,D = \frac{B\,C}{2 \tan \frac{B\,A\,C}{2}} \quad . \quad . \quad . \quad (1)$$

The solution of this equation is practicable, because B C is the space observed, through the telescope, between the points B and C struck by the hairs; and $2 \tan \frac{B\,A\,C}{2}$ is known, because the measuring angle, B A C, is known from the construction of the instrument, and is constant. For simplicity, let k represent the constant value of $2 \tan \frac{B\,A\,C}{2}$, Q the space read on the staff, and D the

distance between the staff and the apex of the measuring angle; then, in place of equation 1—

$$D = \frac{Q}{k} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Practice and experience have shown that, by dividing the staff into special divisions, differing from the unit of measurement, the operations are simplified in a marked degree. The size of each division is made equivalent to a unit of measurement multiplied by k, the constant of the measuring angle. Let g represent the number of these new divisions observed between the hairs; then Q, the actual space, will be g, multiplied by the size of one division, or $Q = g\,k$ and $g = \frac{Q}{k}$; but, by equation (2), $D = \frac{Q}{k}$, therefore—

$$D = g \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

This shows that the number of these special divisions read on a staff gives at once the distance between it and the apex of the measuring angle, which coincides with the vertical axis.

An example will show more clearly the great advantage of this simple arrangement. The measuring angle usually put in the tacheometers made by Troughton and Simms is such that its constant $k = 0 \cdot 02$. When it is desired to measure in yards, then the divisions on the staff are—1 yard $\times$ $0 \cdot 02 = 0 \cdot 02$ yard, that is the $\frac{1}{50}$th part of a yard, or $0 \cdot 72$ inch. If, upon looking with a tacheometer at a staff arranged as mentioned, seventy-five of these divisions are included between the hairs, then the staff is 75 yards away from the instrument; if 100½ divisions are included, it is 100½ yards away, and so on.

Some instruments are made with other measuring angles. Take as a rarity one with a constant such that $k = 0 \cdot 03$, and assume that it is desired to measure in feet, then the divisions on the staff would be 1 foot $\times$ $0 \cdot 03 = 0 \cdot 03$ foot, that is $0 \cdot 36$ inch in size.

It has hitherto been supposed that the staff is held at right-angles to the line of vision; but in work this is obviously impracticable, and it becomes necessary to direct the telescope at a suitable angle, as in Plate 5, Fig. 6, to the staff held vertically. Assume that the central line of vision, I O, strikes the staff at O, forming an angle, V, with the vertical, while the hairs forming the measuring angle strike at M and N. Through O draw a line at right-angles to O I, striking lines of vision of the hairs in

m and n, then O I will represent D in equation (3); $m\,n$ will represent g; and let the number of divisions between M and N be represented by G. The number of divisions between the hairs is usually called the generating number. Owing to the small size of the measuring angle, the lines of sight formed by the hairs are so nearly parallel that the angles, M m O and N n O, may be taken as right-angles,[1] in which case the triangles, M O m and N O n, will be right-angled triangles, whose angles, m M O and n N O, are equal to V, so that $m\,O = M\,O \sin V$ and $n\,O = N\,O \sin V$. Adding these equations, $m\,O + n\,O = (M\,O + N\,O) \sin V$; but $m\,O + n\,O = m\,n$, or g, and $M\,O + N\,O = M\,N$, or G; therefore $g = G \sin V$. By equation (3) $g = D$, therefore $D = G \sin V$.

In Plate 5, Fig. 6, the horizontal distance, H, between the instrument and the staff, the vertical height, T, between the axis of the instrument and the point O, where the central line of vision strikes the staff, and that line of vision, or D, form a right-angled triangle, in which the side D and the angle at O, equal to V, are known. Then $H = D \sin V$; but $D = G \sin V$, therefore $H = (G \sin V) \sin V$, or—

$$H = G \sin {}^2 V \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

which gives a value for the horizontal distance between the instrument and staff, in terms of the angle formed by the telescope with the vertical, and the number of divisions read on the staff when the telescope is thus directed.

The height, T, is deduced thus from the horizontal distance-

$$T = H \operatorname{cotan} V \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

When V is more than a right-angle, that is, when the telescope points downwards, a similar investigation will show that equations (4) and (5) become—

$$H = G \cos {}^2(V\text{—a right-angle}) \quad . \quad (4a)$$
$$T = H \tan (V\text{—a right-angle}) \quad . \quad (5a)$$

By taking into account the height, m, in Plate 5, Figs. 7, 8 and 9, between the ground and the point where the central line of vision strikes the staff, the difference of level is obtained between the instrument and the point on which the staff rests. Let a and b

[1] This assumption gives no error when the telescope is horizontal; the error is inappreciable on ordinary ground; and on a slope of 2 to 1 the error in the horizontal distance is only $\frac{1}{750}$-th part of the whole, with a measuring angle whose constant is 0·02—a result just as good, or better, than any to be obtained by ordinary chainage.

represent the number of divisions between the base of the staff and each place where the hairs cut it, then $\frac{a+b}{2}$ gives the number of divisions between the ground and the point struck by the central line of vision. This number, multiplied by the size of one division, gives the height, m, in units. When a division is 0·02 of a unit of measurement, then $m = \frac{a+b}{2} \times 0 \cdot 02$, or, $m = \frac{a+b}{100}$.

This operation is very simple, as it only consists of adding together the readings of the hairs and placing the decimal point in front of the second figure from the right-hand side. The combinations that are produced relatively between the tacheometer and another station, as far as height is concerned, are shown in Plate 5, Figs. 7, 8 and 9. In Plate 5, Fig. 7, there is a rise from the instrument to the station on which the staff rests; and the difference of level is $T - m$. In Plate 5, Fig. 8, there is a fall; and the difference of level is $T + m$. In Plate 5, Fig. 9, there is also a fall, although the telescope points upwards; and the difference of level is $m - T$. In reducing the field-notes, these combinations require to be carefully watched, so as to properly fix the rises and falls. If the difference of level between the ground at the instrument and at the staff is required, it is necessary to measure with a tape the height of the telescopic axis above the ground, and make the proper allowance.

THE FIELD-WORK.

The chief utility of the tacheometer being the execution of preliminary surveys for projected public works, especially ways of communication, the following explanations will be limited to that use.

Having obtained the variation of the compass, the engineer examines the ground ahead, and then directs the work of his assistants in running a series of traverse lines along the general direction he has adopted. These lines need not coincide exactly with what appears to be the proper alineation, although it is not advisable to separate from it to a very great extent. The instrument is set up at the intersections of all the lines; and these form the principal stations. After measuring the height of the instrument, the first operation at a station is to check the distance to the last one, and the bearing between the two. The difference of level between them ought also to be checked; for, although it is advisable

to find the heights of the main stations independently, yet it is well to bring on in the field a series of levels from station to station, as a reliable appreciation of the general rise or fall of the country is thus gained. The general principles applicable to all compass surveys hold good for checking the bearings, these being read direct off the horizontal plate, by setting its vernier to zero whilst the needle points to the north. To find the distances and heights between the main stations, equations Nos. 4, 5, 4*a* and 5*a*, or the Tables deduced from them, are used. The mean between the back and the last forward observations will give very satisfactory results, if sufficient care is exercised in the readings of the staff and the instrument. When the back line has been thus checked, the details are next taken; and, finally, the forward line is observed. For a topographical plan, roads, streams, rivers, buildings, boundaries of townships, and the prominent features of the country required for delineating contours, ought to be picked up in the zone along which the operations are being conducted. The person in charge directs the men with the staves—two, four, or six in number, according to the expertness of the operators—and, if necessary, makes a sketch of the ground showing where the points are taken. He also takes subsidiary measurements where advisable. Each staff-holder ought to carry a light plumb-line, so as to ensure the verticality of the staff. The stations on the main lines of the traverse may be indicated by letters, and the points for the filling-in by numbers. The numbers may be used consecutively up to 100, and the letters all through the alphabet. All the operators must be in accord as to the number or letter used for each designation. Two persons are required at the instrument, one for directing and reading it, and the other for booking. It is convenient to direct the lower wire at an even number on the staff. When the sight through one of the extreme wires, a, a' (Plate 5, Fig. 4) is intercepted, by reason of trees for instance, the reading of the other is deduced from the central wire. When both are interrupted, then the other set, b, b', is used, taking care to mark this in the field-book in a previously arranged manner. The generating number, in this case, ought to be filled in at once. Assume, for instance, that the wires, b, b', read 89 and 111, and the centre one 100, then the generating number to be entered is 110, or $(111-89) \times 5$, because the constant corresponding to the wires $a\ a'$ is five times that of the wires b, b'. From this it may be deduced that the wires a, a', would have read 45 and 155, if not intercepted; and there are some operators who prefer making the entry thus. The form of book used for making the entries is

given in Appendix I; and in the field it is filled up as far as the eighth column. The order of reading and entry is:—

(i) The readings of the wires. (ii) The vertical angle. (iii) The bearing as shown on the horizontal plate. These entries go on point by point, until all the details corresponding to one station are obtained, and the instrument has to be shifted to the next.

Sights are seldom required at greater distances than 200 yards on either side of the main lines; but, in certain grounds, it may be necessary to take them up to 400 yards, use being made of the wires b, b' (Plate 5, Fig. 4). Where great expedition, and only rough approximations are required, the levelling as found by the tacheometer may be adopted; but in ordinary cases it is most advisable that the heights of the main stations shall be found by a level in the usual way. This entails very little trouble or time; and when done, a plan is produced which, for preliminary work, is incomparably superior to those made by the old systems. Not only is it more speedily executed, but when the contours are laid down, it represents a zone of ground within which all reasonable variations of the proposed trace can be worked up.

The Office-Work.

The first work to be done in the office is to finish the reduction of the field-book. The operation of multiplying every generating number by the sine or cosine squared of the vertical angle, and this result by its tangent or cotangent, would be so tedious that the system of tacheometry would be of no practical value. To overcome this difficulty, the use of the slide-rule was first suggested; and for facilitating its operations, the degrees of the tacheometer were made centesimal. In later years, however, Tables have been formed. They are more exact, and the eyes are not so much strained as when appreciating the divisions of a closely divided rule. The best tables are those of Cuartero, published in Madrid. They can be readily obtained through Messrs. Troughton and Simms; but they refer to centesimal degrees. Tables are given in Appendix II which afford similar results for the ordinary degrees of 90 to a right-angle. The heights are given for every minute, and the distances for every 10 minutes up to 25 degrees. Closer approximations may sometimes be desirable when finding the lengths of the main or traverse lines; and then it will be necessary to use the columns of $\sin^2$ and $\cos^2$ given on the right-hand side of the general tables; but for all ordinary work, a simple interpolation will be quite sufficient. A column is

given for each unit, so that tens will be the same figures with the decimal point placed one figure to the right, and for hundreds, the decimal point will be placed two figures to the right. Having filled in the columns for the heights and distances, the rest of the reductions are taken in hand. The sample-sheet of the field-book (Appendix I) shows clearly how they are executed; and it will be found that they are not more troublesome than those of an ordinary level-book.

The plotting of the plan is next undertaken. When determining the scale, it must be remembered that the operations carried out in the field have been intended only for preliminary studies, so a large scale would be out of place. On a plan drawn to a scale of $\frac{1}{2.500}$, the limit of error is quite inappreciable, and this may be taken as the largest advisable, whilst the smallest desirable for showing public works is perhaps $\frac{1}{5.000}$, which is a little less than 6 chains to an inch.

Having fixed on the general direction to be taken by the plan along the roll of paper, the north is traced on it at a series of convenient places, and the traverse lines are laid down, with a parallel ruler, in the usual way. Rectangular co-ordinates may be used; but the extra work entailed is not usually compensated for by a notably extra degree of correctness. After laying down the main lines, the details are plotted at each station by means of radiating lines, representing the directions and lengths to the points where the staves have been placed. A protractor has been designed to prevent the ugly scoring of the radiating pencil-lines. It is ordinarily made of cardboard, is semicircular in shape, and has the scale of the plan marked along the line of its diameter. It rotates round a needle passed through its centre and the main station, as marked on the paper. By applying the bearing of a point to a north line passing through the main station, the diameter of the protractor really coincides with the direction of the line, and the distance is marked off by the pencil on the scale. Against this mark, its reduced level is written. In this manner all the details taken in the field are put on the plan, use being made at the same time of the notes and independent small measurements made by the engineer in charge of the field-work. Besides the roads, streams, &c., the plan will be studded with dots showing the levels and positions of the culminating points taken for the purpose of representing the natural features of the ground. By means of these levels, contour lines are traced which may be separated from one another in height 2 to 5 metres, or 5, 10, or 15 feet, according to the roughness of the ground. When finished, a plan like this

gives a genuine representation of the country which it is intended to deal with, so that after a few trials, a centre line can be laid down, which will require no further alteration. Longitudinal and cross-sections can be made; and the results of the cubications ought to vary by only a very small percentage from the definite quantities eventually found by means of the working plans.

In Plate 5, Fig. 10, a piece of country is represented mapped out in this way; and Plate 5, Fig. 11, shows the difference between the preliminary and the definite working section of the centre line adopted. This is a case of actual practice on a railway now being constructed. The sample field-book contains some of the operations carried out for forming this plan.

Conclusion.

Many engineers imagine that tacheometry involves a complicated measuring instrument, a number of peculiar accessories, and tedious calculations in the office; but it is hoped that the foregoing explanations will have shown the contrary; for, with an instrument, which is nothing but a transit theodolite, a staff, and simple tables, preliminary plans are produced more rapidly, and giving infinitely more detail, than by the old methods. No doubt a great deal of the suspicion with which this system has hitherto been looked upon was due to the peculiar graduation of 400 degrees to a circle, by which all existing trigonometrical tables are rendered useless; but a careful inquiry at once shows that this is not one of its integral parts. Whenever this fact is generally admitted, a radical change is bound to take place in the make of theodolites. Engineers ought never, in the future, to purchase these as ordinarily constructed, but to insist on the makers supplying them with distance-measuring telescopes, such as are fitted to the present tacheometers. Then tacheometry, which is now looked upon as a special branch of surveying, will pass into one of the ordinary uses of the theodolite.

The Paper is illustrated by four tracings and a photograph, from which Plate 5 has been made.

[Appendixes.

APPENDIXES.

Appendix I.—Field-Book.

WORK											DATE					
Main Stations.	Height of Instrument.	No. of Point.	Bearing.		Vertical Angle.		Reading of Wires.	Generating Number.	Height on Staff.	Horizontal Distance.	Difference in Height.	Rise.	Fall.	Reduced Level.		Remarks.
										$G \sin^2 V$	$H \cot V$	$T-m$.	$m+T$ or $m-T$	Axis of Instrument.	Point or Station.	
					V.			G	m	H	T	+	−			
			Deg.	Min.	Deg.	Min.										
Station A.	1·27	..	..	..	..	..	..	..	..	..	..	..	..	273·97	272·70	
		B.	311	48	91	42	166/10	156	1·76	155·86	4·63	..	6·39	..	267·58	$-6·39+1·27=-5·12$.
		1	96	8	90	32	195/130	65	3·25	65·00	0·61	..	3·86	..	270·11	
		2	88	0	89	36	196/130	66	3·26	66·00	0·46	..	2·80[1]	..	271·17	
		3	87	48	89	32	194/180	70	3·74	70·00	0·57	..	3·17[1]	..	270·80	Central wires.
		4	303	13	94	40	134/60	74	1·94	73·51	6·00	..	7·94[2]	..	266·03	Thrashing floor 20 ms. diam.
Station B.	1·38	..	..	..	..	..	..	..	..	..	..	..	..	268·94	267·56	$\left\{\begin{matrix}-5·12\\+5·15\end{matrix}\right\}5·14$.
		A.	131	50	87	58	166/10	156	1·76	155·80	5·53	3·77	..	..	272·71	$+3·77+1·38=+5·15$.
		C.	296	47	81	52	172/10	162	1·82	158·76	22·69	20·87	..	..	289·81	$+20·87+1·38=+22·25$.
		5	73	10	77	32	174/10	164	1·84	156·31	34·57	32·73[3]	..	..	301·67	
		6	25	8	92	28	155/80	75	2·35	74·86	3·23	..	5·58	..	263·36	

[1] See Fig. 9. [2] See Fig. 8. [3] See Fig. 7.

Appendix II.

90 degrees.

Min.	1	2	3	4	5	6	7	8	9	Min.	
					DISTANCES.						
0	1·0000	2·0000	3·0000	4·0000	5·0000	6·0000	7·0000	8·0000	9·0000	*60*	
10	1·0000	2·0000	3·0000	4·0000	5·0000	6·0000	7·0000	8·0000	9·0000	*50*	
20	1·0000	2·0000	3·0000	4·0000	5·0000	6·0000	7·0000	8·0000	9·0000	*40*	
30	0·9999	1·9998	2·9997	3·9996	4·9995	5·9994	6·9993	7·9992	8·9991	*30*	
					HEIGHTS.						Cos².
0	0	0	0	0	0	0	0	0	0	*60*	1·00000
1	0·0003	0·0006	0·0009	0·001	0·001	0·002	0·002	0·002	0·003	*59*	1·00000
2	0·0006	0·0012	0·0018	0·002	0·003	0·004	0·004	0·005	0·005	*58*	1·00000
3	0·0009	0·0018	0·0027	0·004	0·004	0·005	0·006	0·007	0·008	*57*	1·00000
4	0·0012	0·0023	0·0035	0·005	0·006	0·007	0·008	0·009	0·010	*56*	1·00000
5	0·0014	0·0029	0·0043	0·006	0·007	0·008	0·010	0·011	0·013	*55*	0·99999
	0·0017	0·0035	0·0052	0·007	0·009	0·010	0·012	0·014	0·015	*54*	0·99999
7	0·0020	0·0041	0·0061	0·008	0·010	0·012	0·014	0·016	0·018	*53*	0·99999
8	0·0023	0·0047	0·0070	0·010	0·012	0·014	0·016	0·019	0·021	*52*	0·99999
9	0·0026	0·0052	0·0079	0·011	0·013	0·016	0·018	0·021	0·024	*51*	0·99999
10	0·0029	0·0058	0·0087	0·012	0·014	0·017	0·020	0·023	0·026	*50*	0·99999
11	0·0032	0·0064	0·0096	0·013	0·016	0·019	0·022	0·025	0·029	*49*	0·99999
12	0·0035	0·0070	0·0105	0·014	0·017	0·021	0·024	0·028	0·031	*48*	0·99999
13	0·0038	0·0076	0·0114	0·015	0·019	0·023	0·027	0·030	0·034	*47*	0·99999
14	0·0041	0·0081	0·0122	0·016	0·020	0·025	0·029	0·033	0·037	*46*	0·99999
15	0·0044	0·0087	0·0131	0·017	0·022	0·026	0·031	0·035	0·039	*45*	0·99998
16	0·0047	0·0093	0·0140	0·019	0·023	0·028	0·033	0·037	0·042	*44*	0·99998
17	0·0049	0·0099	0.0148	0·020	0·025	0·029	0·035	0·039	0·044	*43*	0·99998
18	0·0052	0·0105	0·0157	0·021	0·026	0·031	0·037	0·042	0·047	*42*	0·99997
19	0·0055	0·0111	0·0166	0·022	0·027	0·033	0·039	0·044	0·050	*41*	0·99997
20	0·0058	0·0116	0·0174	0·023	0·029	0·035	0·041	0·046	0·052	*40*	0·99996
21	0·0061	0·0122	0·0183	0·024	0·030	0·037	0·043	0·049	0·055	*39*	0·99996
22	0·0064	0·0128	0·0192	0·026	0·032	0·038	0·045	0·051	0·058	*38*	0·99996
23	0·0067	0·0134	0·0201	0·027	0·033	0·040	0·047	0·054	0·060	*37*	0·99996
24	0·0070	0·0140	0·0209	0·028	0·035	0·042	0·049	0·056	0·063	*36*	0·99995
25	0·0073	0·0146	0·0218	0·029	0·036	0·044	0·051	0·058	0·065	*35*	0·99995
26	0·0076	0·0151	0·0227	0·030	0·038	0·046	0·053	0·060	0·068	*34*	0·99994
27	0·0078	0·0157	0·0235	0·032	0·039	0·047	0·055	0·063	0·071	*33*	0·99994
28	0·0081	0·0163	0·0244	0·033	0·041	0·049	0·057	0·065	0·073	*32*	0·99993
29	0·0084	0·0169	0·0253	0·034	0·042	0·051	0·059	0·068	0·076	*31*	0·99993
30	0·0087	0·0174	0·0262	0·035	0·044	0·053	0·061	0·070	0·079	*30*	0·99992
					89 degrees.						Sine².

Appendix II.

90 degrees.

Min.	1	2	3	4	5	6	7	8	9	Min	
					DISTANCES.						
30	0·9999	1·9998	2·9997	3·9996	4·9995	5·9994	6·9993	7·9992	8·9991	*30*	
40	0·9999	1·9998	2·9997	3·9996	4·9995	5·9994	6·9993	7·9992	8·9991	*20*	
50	0·9998	1·9996	2·9994	3·9992	4·9990	5·9988	6·9986	7·9984	8·9982	*10*	
60	0·9997	1·9994	2·9991	3·9988	4·9985	5·9982	6·9979	7·9976	8·9973	*0*	
					HEIGHTS.						Cos².
30	0·0087	0·0174	0·0262	0·035	0·044	0·053	0·061	0·070	0·079	*30*	0·99992
31	0·0090	0·0180	0·0270	0·036	0·045	0·054	0·063	0·072	0·081	*29*	0·99992
32	0·0093	0·0186	0·0279	0·037	0·046	0·056	0·065	0·074	0·084	*28*	0·99991
33	0·0096	0·0192	0·0288	0·038	0·048	0·058	0·067	0·077	0·086	*27*	0·99991
34	0·0099	0·0198	0·0297	0·040	0·049	0·059	0·069	0·079	0·089	*26*	0·99990
35	0·0102	0·0204	0·0306	0·041	0·051	0·061	0·071	0·082	0·092	*25*	0·99990
36	0·0105	0·0210	0·0315	0·042	0·052	0·063	0·073	0·084	0·094	*24*	0·99989
37	0·0108	0·0216	0·0324	0·043	0·054	0·065	0·076	0·086	0·097	*23*	0·99988
38	0·0111	0·0222	0·0332	0·044	0·055	0·067	0·078	0·089	0·100	*22*	0·99988
39	0·0113	0·0227	0·0340	0·045	0·056	0·068	0·080	0·090	0·102	*21*	0·99987
40	0·0116	0·0232	0·0348	0·046	0·058	0·070	0·082	0·093	0·104	*20*	0·99986
41	0·0119	0·0238	0·0357	0·048	0·059	0·071	0·084	0·095	0·107	*19*	0·99986
42	0·0122	0·0244	0·0366	0·049	0·061	0·073	0·086	0·098	0·110	*18*	0·99985
43	0·0125	0·0250	0·0375	0·050	0·063	0·075	0·088	0·100	0·112	*17*	0·99984
44	0·0128	0·0256	0·0384	0·051	0·064	0·077	0·090	0·102	0·115	*16*	0·99984
45	0·0131	0·0262	0·0393	0·052	0·065	0·079	0·092	0·105	0·118	*15*	0·99983
46	0·0134	0·0268	0·0402	0·054	0·067	0·080	0·094	0·107	0·121	*14*	0·99983
47	0·0137	0·0274	0·0411	0·055	0·068	0·082	0·096	0·110	0·123	*13*	0·99982
48	0·0140	0·0280	0·0420	0·056	0·070	0·084	0·098	0·112	0·126	*12*	0·99981
49	0·0143	0·0286	0·0429	0·057	0·071	0·086	0·100	0·114	0·129	*11*	0·99980
50	0·0145	0·0291	0·0437	0·058	0·072	0·087	0·102	0·116	0·131	*10*	0·99979
51	0·0148	0·0296	0·0445	0·059	0·074	0·089	0·104	0·118	0·133	*9*	0·99978
52	0·0151	0·0302	0·0453	0·060	0·075	0·091	0·106	0·121	0·136	*8*	0·99977
53	0·0154	0·0308	0·0462	0·062	0·077	0·092	0·108	0·123	0·139	*7*	0·99976
54	0·0157	0·0314	0·0471	0·063	0·078	0·094	0·110	0·126	0·141	*6*	0·99975
55	0·0160	0·0320	0·0480	0·064	0·080	0·096	0·112	0·128	0·144	*5*	0·99974
56	0·0163	0·0326	0·0489	0·065	0·081	0·098	0·114	0·130	0·147	*4*	0·99973
57	0·0166	0·0332	0·0498	0·066	0·083	0·100	0·116	0·133	0·149	*3*	0·99972
58	0·0169	0·0338	0·0506	0·068	0·084	0·101	0·118	0·135	0·152	*2*	0·99971
59	0·0172	0·0343	0·0514	0·069	0·086	0·103	0·120	0·137	0·154	*1*	0·99970
60	0·0174	0·0348	0·0522	0·070	0·087	0·104	0·122	0·139	0·157	*0*	0·99969
					89 degrees.						Sine².

Appendix II.

120 degrees.

Min.	1	2	3	4	5	6	7	8	9	Min.	
					DISTANCES.						
0	0·7500	1·5000	2·2500	3·0000	3·7500	4·5000	5·2500	6·0000	6·7500	60	
10	0·7475	1·4950	2·2425	2·9900	3·7375	4·4850	5·2325	5·9800	6·7275	50	
20	0·7449	1·4898	2·2347	2·9796	3·7245	4·4694	5·2143	5·9592	6·7041	40	
30	0·7424	1·4848	2·2272	2·9696	3·7120	4·4544	5·1968	5·9392	6·6816	30	
					HEIGHTS.						Cos².
0	0·4330	0·8660	1·2990	1·732	2·165	2·598	3·031	3·464	3·897	60	0·75000
1	0·4331	0·8663	1·2994	1·732	2·165	2·599	3·032	3·465	3·898	59	0·74975
2	0·4333	0·8666	1·2999	1·733	2·166	2·600	3·033	3·466	3·900	58	0·74950
3	0·4334	0·8669	1·3003	1·734	2·167	2·601	3·034	3·467	3·901	57	0·74924
4	0·4336	0·8672	1·3008	1·734	2·168	2·602	3·035	3·469	3·902	56	0·74899
5	0·4337	0·8675	1·3012	1·735	2·168	2·602	3·036	3·470	3·903	55	0·74874
6	0·4339	0·8678	1·3017	1·736	2·169	2·603	3·037	3·471	3·905	54	0·74849
7	0·4340	0·8680	1·3021	1·736	2·170	2·604	3·038	3·472	3·906	53	0·74823
8	0·4341	0·8683	1·3025	1·737	2·170	2·605	3·039	3·473	3·907	52	0·74798
9	0·4343	0·8686	1·3029	1·737	2·171	2·606	3·040	3·474	3·909	51	0·74773
10	0·4344	0·8689	1·3033	1·738	2·172	2·607	3·041	3·475	3·910	50	0·74748
11	0·4346	0·8692	1·3037	1·738	2·173	2·608	3·042	3·477	3·911	49	0·74722
12	0·4347	0·8694	1·3041	1·739	2·173	2·608	3·043	3·478	3·912	48	0·74697
13	0·4349	0·8697	1·3045	1·740	2·174	2·609	3·044	3·479	3·914	47	0·74672
14	0·4351	0·8700	1·3050	1·740	2·175	2·610	3·045	3·481	3·916	46	0·74656
15	0·4352	0·8703	1·3055	1·741	2·176	2·611	3·046	3·482	3·917	45	0·74621
16	0·4353	0·8706	1·3059	1·741	2·176	2·612	3·047	3·483	3·918	44	0·74596
17	0·4355	0·8709	1·3064	1·742	2·177	2·613	3·048	3·484	3·919	43	0·74570
18	0·4356	0·8712	1·3068	1·742	2·178	2·614	3·049	3·485	3·920	42	0·74545
19	0·4357	0·8715	1·3072	1·743	2·178	2·614	3·050	3·486	3·921	41	0·74520
20	0·4359	0·8718	1·3077	1·744	2·179	2·615	3·051	3·487	3·923	40	0·74494
21	0·4360	0·8721	1·3081	1·744	2·180	2·616	3·052	3·488	3·924	39	0·74469
22	0·4362	0·8724	1·3086	1·745	2·181	2·617	3·053	3·489	3·926	38	0·74444
23	0·4363	0·8727	1·3090	1·745	2·181	2·618	3·054	3·490	3·927	37	0·74418
24	0·4365	0·8730	1·3094	1·746	2·182	2·619	3·055	3·492	3·928	36	0·74393
25	0·4366	0·8733	1·3099	1·746	2·183	2·620	3.056	3·493	3·929	35	0·74368
26	0·4367	0·8735	1·3103	1·747	2·184	2·620	3·057	3·494	3·930	34	0·74342
27	0·4369	0·8738	1·3107	1·747	2·184	2·621	3·058	3·495	3·932	33	0·74317
28	0·4370	0·8740	1·3111	1·748	2·185	2·622	3·059	3·496	3·933	32	0·74291
29	0·4371	0·8743	1·3115	1·748	2·185	2·623	3·060	3·497	3·934	31	0·74266
30	0·4373	0·8746	1·3119	1·749	2·186	2·624	3·061	3·498	3·936	30	0·74240
					59 degrees.						Sine².

Appendix II.

120 degrees.

Min.	1	2	3	4	5	6	7	8	9	Min.	
					DISTANCES.						
30	0·7424	1·4848	2·2272	2·9696	3·7120	4·4544	5·1968	5·9392	6·6816	30	
40	0·7399	1·4798	2·2197	2·9596	3·6995	4·4394	5·1793	5·9192	6·6591	20	
50	0·7373	1·4746	2·2119	2·9492	3·6865	4·4238	5·1611	5·8984	6·6357	10	
60	0·7347	1·4694	2·2041	2·9388	3·6735	4·4082	5·1429	5·8776	6·6123	0	
					HEIGHTS.						Cos².
30	0·4373	0·8746	1·3119	1·749	2·186	2·624	3·061	3·498	3·936	30	0·74240
31	0·4374	0·8749	1·3123	1·750	2·187	2·624	3·062	3·499	3·937	29	0·74215
32	0·4376	0·8752	1·3127	1·750	2·188	2·625	3·063	3·501	3·938	28	0·74190
33	0·4377	0·8755	1·3131	1·751	2·188	2·626	3·064	3·502	3·939	27	0·74164
34	0·4379	0·8758	1·3135	1·751	2·189	2·627	3·065	3·503	3·941	26	0·74139
35	0·4380	0·8760	1·3140	1·752	2·190	2·628	3·066	3·504	3·942	25	0·74113
36	0·4381	0·8763	1·3144	1·752	2·190	2·629	3·067	3·505	3·943	24	0·74089
37	0·4383	0·8766	1·3149	1·753	2·191	2·630	3·068	3·506	3·945	23	0·74062
38	0·4384	0·8769	1·3153	1·754	2·192	2·631	3·069	3·507	3·946	22	0·74037
39	0·4386	0·8772	1·3157	1·754	2·193	2·632	3·070	3·508	3·947	21	0·74011
40	0·4387	0·8774	1·3161	1·755	2·193	2·632	3·071	3·509	3·948	20	0·73986
41	0·4388	0·8777	1·3165	1·755	2·194	2·633	3·072	3·510	3·949	19	0·73960
42	0·4389	0·8779	1·3169	1·756	2·194	2·633	3·073	3·511	3·950	18	0·73935
43	0·4391	0·8782	1·3173	1·756	2·195	2·634	3·074	3·513	3·952	17	0·73909
44	0·4392	0·8785	1·3177	1·757	2·196	2·635	3·075	3·514	3·953	16	0·73883
45	0·4394	0·8788	1·3182	1·758	2·197	2·636	3·076	3·515	3·955	15	0·73858
46	0·4395	0·8791	1·3186	1·758	2·197	2·637	3·077	3·516	3·956	14	0·73832
47	0·4397	0·8794	1·3190	1·759	2·198	2·638	3·078	3·517	3·957	13	0·73807
48	0·4398	0·8797	1·3194	1·759	2·199	2·639	3·079	3·518	3·958	12	0·73780
49	0·4399	0·8799	1·3198	1·760	2·199	2·640	3·080	3·519	3·959	11	0·73756
50	0·4401	0·8802	1·3203	1·760	2·200	2·641	3·081	3·521	3·961	10	0·73730
51	0·4402	0·8805	1·3207	1·761	2·201	2·641	3·082	3·522	3·962	9	0·73704
52	0·4404	0·8808	1·3212	1·762	2·202	2·642	3·083	3·523	3·663	8	0·73679
53	0·4405	0·8810	1·3216	1·762	2·202	2·643	3·084	3·524	3·964	7	0·73653
54	0·4407	0·8813	1·3221	1·763	2·203	2·644	3·085	3·525	3·966	6	0·73638
55	0·4408	0·8816	1·3225	1·763	2·204	2·645	3·086	3·526	3·967	5	0·73602
56	0·4409	0·8819	1·3229	1·764	2·204	2·646	3·087	3·527	3·968	4	0·73576
57	0·4411	0·8822	1·3233	1·764	2·205	2·647	3·088	3·529	3·970	3	0·73551
58	0·4412	0·8825	1·3237	1·765	2·206	2·647	3·089	3·530	3·971	2	0·73525
59	0·4414	0·8828	1·3241	1·766	2·207	2·648	3·090	3·531	3·972	1	0·73499
60	0·4415	0·8830	1·3245	1·766	2·207	2·649	3·091	3·532	3·973	0	0·73474
					59 degrees.						Sine².

APPENDIX II—*continued.*—EXPLANATION OF TABLES.

The manner of using the Tables is shown in the following example, which is point 5 in the field-book.

The generating number (G), is 164, the vertical angle (V), is 77° 32′, and is required to find the horizontal distance (H), and the difference of height (T), between the point and the main station. Look along the line representing 77° 32′, in that part of the page dedicated to heights, and in the

Column	marked	1	is	0·2108
,,	,,	6	,,	1·2650
,,	,,	4	,,	0·8430

The nearest angle on that part of the page dedicated to distances is 77° 30′ and in the

Column	marked	1	is	0·9531
,,	,,	6	,,	5·7186
,,	,,	4	,,	3·8124

These numbers are operated thus:—

G.	H.	T.
100	95·31	21·08
60	57·19	12·65
4	3·81	0·84
164	156·31	34·57

Had this been a line between two main stations it would have been advisable to proceed with more care when finding the distance. The generating number would be multiplied by the $\sin^2$ or $\cos^2$ of the vertical angle, which, in the example, is 0·95340; so that $164 \times 0·9534 = 156·36$.

*** The Tables are published in full in the Pamphlet form of the Paper, which will be supplied to any member who applies for it.—SEC. INST. C.E.

(*Paper No. 2393.*)

"Some Recently Constructed Piers and Harbours on the North and West Coasts of Scotland."

By JAMES BARRON, M. Inst. C.E.

THE necessity for increased harbour- and pier-accommodation on the north and west coasts of Scotland has been pressing itself on the attention of the Government, and also on landed proprietors whose properties are mainly tenanted by crofters and fishermen.

Recent changes, and the depression in agriculture amongst the crofters and cottars of the Highlands and Islands, require that better harbour facilities should be given them, as they are now more than ever dependent for subsistence on the produce of the sea. Proprietors are also realizing the fact that in future they must look more to the sea than to the land for their income.

It is therefore of great importance that harbour accommodation be given for shipping fish and agricultural produce rapidly to large centres of population.

From the annual returns of the Fishery Board for Scotland, it appears that the number of persons employed at the fishing industry on the north and west coasts is nearly twenty-seven thousand, and there are four thousand six hundred fishing-boats, with nets and gear, representing a capital of £202,000; while the value of the fish caught during the year 1887 amounted to £180,000.

Fortunately, the western shores of Scotland, and the east side of the outer Hebrides, are indented with numerous natural harbours, which, for depth of water and accommodation, cannot be surpassed, affording excellent shelter for all classes of vessels, without the aid of breakwaters or piers involving great cost for construction; therefore, what is required are piers of a simple yet substantial character, fit to withstand the shocks to which they are liable from steamers, and erected in sufficient depth of water to permit of vessels approaching them at all states of the tide.

The Author thinks that a concise account of a few of these piers and harbours may be of interest. The following is a brief description, along with some particulars of cost, of several structures erected by him:—

(1) Castle Bay, Barra, Inverness.

(2) Loch Boisdale, South Uist, Inverness.
(3) Loch Skipport, South Uist, Inverness.
(4) Stornoway, Lewis, Ross.
(5) Loch Inchard, Sutherland.
(6) Loch Eriboll, Sutherland (Plate 6).

Sites and Form of Plans.

In selecting the sites for these piers, which are designed to accommodate fishing-vessels and steamers of a large class, the following points were kept in view:—

Accessibility from the sea, and proximity to existing roads on the land.

Sufficient depth of water, that vessels may be water-borne at all states of the tide.

Suitability of the ground for holding piles.

It is also desirable that the immediately adjoining shore, at both ends of the piers above high-water mark, should be adapted for placing mooring-rings, or palls, in such position that large vessels may conveniently use them for stem and stern moorings, the advantage of this arrangement being that the pier may be made with less frontage than would otherwise be necessary for large vessels to berth at.

The form or plan of these piers was determined by the suitability of the ground for holding piles, and the local requirements in the way of accommodation for traffic.

Where the necessary depth of water and holding ground was found close to the shore, as at Loch Skipport and Loch Boisdale, the section adopted was more economical than at Loch Inchard, where a considerable amount of building is required in forming an access, the masonry of which is continued to low-water mark, and there joins the timber pier, which is T form on plan.

The section adopted at Stornoway forms retaining-walls for ground required for harbour purposes.

Materials and Construction.

Although stone of a very rough description is abundant near the sites of all the piers, the expense of quarrying the stones of suitable dimensions, and of building walls on soft ground and in deep water, was found to be much too great; and as there happened to be good holding-ground for piles, it was cheaper to construct the piers of greenheart, it being the only description of timber

able to resist the ravages of the teredo. As a matter of economy, pitch-pine was used above high-water mark.

It was found that the roads or means of access, when formed with stone, were relatively costly. This arose from the fact that generally no roads existed near the sea-shore. Thus a considerable amount of building in retaining-walls was required, and in some cases rock-cutting was necessary.

Briefly, the works were thus executed:—The piers were constructed of Demerara greenheart timber, with the exception of the top beams, joists, flooring or planking, and protecting rail, which were of pitch-pine; the fenders, on the outer faces of the piers, were of American elm. The piles were cut square on the upper end, to prevent the piling-ram from splitting them. The temporary pile-rings were of wrought-iron, 3 inches broad by 1 inch thick, fitted and driven on tight. Temporary bolts were put through any pile which showed signs of splitting while being driven. The pile-shoes were carefully fitted, with the point of the shoe exactly in the centre of the pile. Temporary bolts, shores and tackle were used, in order that the piles might be driven straight.

The best of the piles were selected for the front rows, and adzed on the outer face, that the elm fender-piles might bear evenly on them.

The cross-ties and diagonal stays were in one length; all the ties and stays were bedded fair where surfaces met on the piles; and when any pile was out of line, or off the square, a bulking-piece of greenheart timber was carefully fitted between the timbers before being bolted. The walings were put on in lengths to break bond on the piles. The planking, or roadway of the piers, was in breadths of 10 inches and 12 inches, and fastened with wrought-iron spikes ½ inch in diameter, 8 inches long, with countersunk heads, two spikes in each plank on joist. A clear space, ½ inch wide, was left between each plank, and slips of timber, ½ inch thick, were inserted between them so far as resting on the joists. All the timber was thoroughly coated with pitch-oil and coal-tar. The wrought-iron in the pile-shoes, bolts, spikes, and plate-washers was of a quality equal to N.B. best crown iron. The cast-iron washers were of the toughest grey iron.

Annexed is a detailed statement of the cost of Castle Bay Pier, the rates and prices for the others being similar. The piles were driven by a manual piling-engine, with ram weighing 15 cwt. Temporary staging was constructed with the timbers subsequently used in the piers, care being taken to fasten it with chain-lashings and hardwood wedges, to avoid damage by boring for bolt-holes.

DETAILED STATEMENT of COST of PIER at CASTLE BAY, BARRA.

—		Lineal Feet.	Loads.	Rate per Load at Liverpool.	Freight per Load.	Labour, Erecting per Lineal Foot.	Cost of Materials.	Cost of Labour.	Totals.
	Ins. Ins.			£. s. d.	s. d.	d.	£. s. d.	£. s. d.	£. s. d.
Greenheart piles,	12 × 12 .	2,800	62	7 10 0	10 0	7½	496 0 0	87 10 0	583 10 0
" walings,	12 × 6 .	1,600	17½	7 10 0	10 0	5	140 0 0	33 6 8	173 6 8
" stays,	12 × 6 .	1,330	14½	7 10 0	10 0	4½	116 0 0	24 18 9	140 18 9
Pitch-pine beams,	12 × 6 .	1,200	12	4 3 6	7 6	4	54 12 0	20 0 0	74 12 0
" " "	10 × 10 .	330	4½	4 3 6	7 6	3½	20 9 6	4 16 3	25 5 9
" " joists,	10 × 4½ .	1,000	7	4 3 6	7 6	3½	31 17 0	14 11 8	46 8 8
" " planking,	12 × 4 .	5,200	34½	4 3 6	7 6	1	156 19 6	21 13 4	178 12 10
American elm fenders,	12 × 6 .	646	6½	5 0 0	7 6	5	34 18 9	13 9 2	48 7 11
IRON, &c.					Cwt.	Rate.			
						s. d.			
Cast-iron in washers					9	9 6	4 5 6	..	4 5 6
Wrought-iron in washers . . .					1	15 3	0 15 3	..	0 15 3
" screwed-bolts . . .					58	10 6	30 9 0	..	30 9 0
" pile-shoes					15¾	17 6	13 15 7	..	13 15 7
" spikes					15	13 0	9 15 0	..	9 15 0
Pitch-oil							5 0 0	..	5 0 0
Prepared coal-tar							6 0 0	..	6 0 0
						£	1,120 17 1	220 5 10	1,341 2 11
Goods shed and office									200 0 0
Forming accesses									150 0 0
Engineering, and cost of provisional order									200 0 0
Total cost of pier									1,891 2 11

NOTE.—An allowance of 10 per cent. is given in excess of the quantity of greenheart specified, as that class of timber cannot be obtained in log nearer the dimensions required.

The piers are now being used by the large passenger and cargo steamers owned by Messrs. McBrayne, Glasgow; Langlands, Liverpool; and others; some of these well-known vessels, such as the "Claymore" and "Clansman," are 227 feet in length, with a registered tonnage of 420 tons.

Board of Trade provisional orders, entitling the authorities to levy dues and rates, were obtained for the piers at Castle Bay, Loch Boisdale, and Loch Skipport, and the whole cost of their erection was borne by Lady Gordon Cathcart, proprietrix of South Uist and Barra. A provisional order was also obtained by the Pier and Harbour Commissioners for the construction of the pier at Stornoway. The pier at Loch Inchard was erected by, and at the sole cost of, the Duke of Sutherland, K.G., Hon. M. Inst. C.E. The site of this pier was recommended by the Crofter Commission of 1883, and no dues are levied. The pier at Loch Eriboll was constructed by the Fishery Board for Scotland, which contributed three-fourths of the cost, the balance being made up by the Duke of Sutherland. The piers were executed under the Author's superintendence, without the intervention of a contractor.

The communication is illustrated by several drawings, from a selection of which Plate 6 has been engraved.

(*Paper No. 2420.*)

"Progress of Inland Steam-Navigation in North-East India from 1832."

By Alexander Joseph Bolton, M. Inst. C.E.

As a short description of the inland steamer services connected with the Ganges and Brahmapootra may prove of interest to the members of the Institution, the Author has endeavoured to give, as briefly as possible, a general outline of each, and to show the progress made since the date of the introduction of the former by the late Honourable East India Company.

This service was inaugurated in 1832, and comprised the following steam-vessels, namely "Lord William Bentinck," "Thames," "Brahmapootra," "Megna," "Jumna," "Indus," "Hurringutta," "Damooda," "Nerbudda," and "Mahanuddy." The above-named were the first steamers plying on the River Ganges, from 1832 to 1840; and their principal dimensions were: length, 140 feet; beam, 25 feet; and depth, 8 feet. They were fitted with oscillating engines of 60 nominal HP., and flue-boilers, working at a pressure of 7 lbs. per square inch, constructed by Messrs. Maudslay and Company, London. In 1857, the "Koel" and "Kolydyne" were added, of larger dimensions. Their engines were of 90 nominal HP., with rectangular multitubular boilers of 20 lbs. per square inch working-pressure. The hull, engines, and boilers were constructed by Messrs. Napier and Company, Glasgow. During the period of the Mutiny, and after the transfer of the East India Company to the Crown, still more important additions were made by the Government to the inland flotilla, notably the "Sir William Peel" and "Jabuna," fitted with oscillating engines of 120 nominal HP., by Messrs. James Watt and Company, Soho, Birmingham; and the "Ganges," the hull of which, together with the machinery, was constructed at the Government dockyard, Calcutta, by means of native labour. This was considered no small feat in those days. The fleet was further increased by the addition of the "Tay," "Spey," "Teviot," and "Tweed," designed by Mr. T. B. Winter, M. Inst. C.E., of the following dimensions:—Extreme length, 239 feet 6 inches; beam, 38 feet; depth of hold, 5 feet. The hulls, engines, and boilers were constructed by Messrs. Laird and Co., of Birkenhead. All the steamers of the latter class were large and

powerful, suited in every respect for the conveyance of troops and stores, and did good service for the Government. This was the pioneer flotilla on these waters, and for the greater portion of its existence was both a Government and a commercial service combined, being utilized for the conveyance of troops and Government stores as well as passengers and merchandise to and from Calcutta to the terminal station Allahabad, at the junction of the River Ganges and Jumna, a distance by river of 1,000 miles.

During the first Burmese war, a portion of the Government flotilla was told off for duty on the Irrawaddy, where a dockyard was established at Dallah. The vessels were afterwards sold to the Irrawaddy Flotilla Company, and formed the nucleus of this celebrated and powerful company's fleet. The Government finally decided, in 1865, to dispose of the flotilla in Bengal, reserving one or two steamers only for purely Government purposes, and thus terminated a service which had done good work both for the Government and the public for a period of thirty-three years.

The India General Steam-Navigation Company, Limited, was incorporated on the 6th of February, 1844, with a capital of 18 lakhs. The first steamers were the "Sir Frederick Currie," "General McCloud," "Charles Allen," "Lady Thackwell," "James Hume," "Calcutta," "Bombay," "Madras," "Colgong," "Rajmahal," "Agra," "Lahore," and "Simla," fitted with the different types of paddle-wheels then in vogue. The above steamers were built as circumstances required from the year 1844 to 1861, and generally followed the lines of the Government vessels in respect to construction and details, but of greater power. The chief departures as regards dimensions and HP. were made in the four last vessels, namely, the "Rajmahal," "Agra," "Lahore," and "Simla," their principal dimensions being: length, 225 feet; beam, 28 feet; depth, 9 feet. There was a still further advance in boiler-pressure, and power of engines. The tea industries of Assam and Cachar gave, however, the greatest impetus to inland navigation, and the company's fleet was found inadequate to cope with the increasing demands made upon it. In 1844 it consisted of half a dozen steamers with a few cargo barges or flats; it has now risen, in 1889, to a fleet of well-equipped vessels, comprising sixty-one steamers, and seventy-three flats, some of which are chartered from the Eastern Bengal State Railway. This will serve to illustrate the rapid strides inland navigation has made since the formation of the India General Steam-Navigation Company in 1844, and it must be remembered that the Rivers Steam-Navigation Company, the

Eastern Bengal State Railway, and the Calcutta Steam-Navigation Company also possess at the present time large and powerful flotillas. The latter company's vessels are principally employed as a native passenger service, and are commanded by natives on deck and in the engine-room. Native drivers can take charge of an engine with cylinders 22 inches and 43 inches in diameter respectively, irrespective of stroke and other conditions.

The following rules for calculating the HP. of engines have been officially published by the Government of Bengal:—

1. For ordinary condensing engines:—
   D = diameter of cylinder in inches.
   N = number of cylinders.

$$\frac{D^2 \times N}{30} = \text{N HP.}$$

2. For compound condensing engines—
   D = diameter of low-pressure cylinders in inches.
   d = diameter of high-pressure cylinders in inches.
   N = number of low-pressure cylinders.
   n = number of high-pressure cylinders.

$$\frac{(d^2 \times n) + (D^2 \times N)}{30} = \text{N HP.}$$

The rapid means of transit inaugurated by the East Indian Railway must be regarded as an element of competition in reference to river-borne traffic on the Ganges, and taken in conjunction with the difficulties of navigation, it has made the company look elsewhere for more remunerative employment. It was in consequence of this opposition that the India General Steam-Navigation Company, in 1861, first commenced running vessels on the Brahmapootra. However, as regards railway versus river-borne traffic, it must be understood in the case of the Ganges that impediments in navigation proved the greatest obstacles to the successful employment of steamers; and the Author is of opinion that, if steamers properly designed to suit the requirements of the Ganges were adopted, there is yet a good remunerative traffic to be done as far as Dinapore and Revelgunge, tapping all the stations on the north side of the river. Coals can now be obtained on the Ganges at reasonable rates. The India General Steam-Navigation Company has again commenced this old service with

fairly good results; but the company is so largely interested in the jute and tea industries, that the Ganges does not receive the attention it deserves. The Brahmapootra has a great advantage over the Ganges as a navigable river, being comparatively free from impediments, and steamers with a draught of from 5 feet to 6 feet make the voyage to Dibrugarh and back without serious difficulties or delays. The channels are worse in some years than in others, as the volume of water in the river depends in a great measure upon the melting of the snows on the Himalayan range; but during the dry season, from November to the end of May, the channels are constantly changing, and shifting sands and strong currents are met with, rendering navigation difficult.

The process of towing one or two cargo flats, with a carrying capacity of from 600 tons to 1,000 tons, from Calcutta to Dibrugarh by way of the Sunderbunds, and during the rains by the Hooghly as far as its junction with the Ganges, was necessarily a slow one. A faster service was required, and the Assam Government put itself in communication with the two leading inland flotilla companies, with a view to getting better means of communication for passengers and mails. Messrs. Macneill and Company, on the offer of a subsidy, guaranteed a daily despatch service of four days from Dhubri to Dibrugarh, the vessels to be of light draught, high speed, and limited carrying capacity. The order for the construction of the steamers was entrusted by Messrs. Macneill and Company to Mr. Josiah McGregor, M. Inst. C.E., London, a gentleman of large experience in the construction of steamers of light draught for river service. The vessels designed by Mr. McGregor realized expectations in every respect, and are to the present day doing good service from Dhubri to Dibrugarh, running in connection with the Eastern Bengal Railway system from Dhubri. This service is very much accelerated in comparison with the old routes and systems, and would be still more appreciated if it were not for the frequent railway breaks, necessitated by having to cross three large rivers on the way in ferry-steamers and country boats.

To keep pace with the times, the India General Steam-Navigation Company constructed, at its dockyard, three despatch steamers of 215 feet length, 28 feet beam, and 9 feet depth of hold, fitted with triple-expansion engines indicating 800 HP., with every convenience for passengers. These vessels run in connection with the Eastern Bengal State Railway from Goalundo to Dibrugarh, and the route is very popular with passengers, as there is only one railway journey of nine hours, and there are no breaks when once

on board the steamer. The time occupied on the journey compares also favourably with the mail-service line.

As the mail service to Assam had been greatly accelerated by the adoption of a special class of steamers, it was decided to place the province of Cachar on the same favourable footing, by establishing a service for the conveyance of passengers and mails, and the Assam Government, in 1886, entered into negotiations with the India General Steam-Navigation Company, which resulted in its accepting the Company's offer to construct eight vessels 160 feet long, by 22 feet beam by 7 feet 8 inches depth, the conditions being similar, in every respect, to the Assam service. The vessels were constructed from designs submitted by the Author. Hulls and fittings, with all cabin accommodation, were entirely built at the Company's dockyard; and the diagonal compound surface-condensing engines, cylinders 18 inches and 36 inches respectively, and 42 inches stroke, indicating 326 HP., were constructed by Messrs. Bow, McLachlan and Company, Paisley. The speed attained was 11·6 miles per hour. The service has, as regards speed and draught, answered expectations, and the vessels have proved a great acquisition to the planters of Cachar, as they are now placed in quick and regular communication with Calcutta. The large steamers are generally used for towing cargo flats; but the Author believes that the time is not far distant when this mode of conveyance will be entirely confined to the lower water of the Ganges, from Naraingunge and Serajganj, in the carriage of jute and other commodities through the Sunderbunds to Calcutta; and that single-handed powerful steamers will be the means of communication on the upper waters from Goalundo to Dibrugarh. The Author has now shown what a great advance has been made in the dimensions of river steamers since the days of the pioneer vessels, which were 140 feet long by 25 feet beam, and which were then considered to be so large as to be difficult to handle in some of the intricate channels of the Sunderbunds, the delta of the Ganges, and the Brahmapootra. The steamers of the present day, 250 feet to 280 feet long and 30 feet to 40 feet beam, are, however, no more difficult to handle than the early vessels. The vessels have been fitted with compound triple- and quadruple-expansion engines, with surface condensers and all the latest improvements. The Author is of opinion that, for river work, nothing beats the ordinary compound engines, especially if they are to be in charge of native drivers; and native labour is being greatly utilized, and will be more largely employed in the near future. On deck are to be found all modern appliances, such as steam steering-

gear and steam windlasses; and the passenger accommodation, if not luxurious, is very comfortable and adapted to the requirements of the climate.

In 1857 Mr. T. B. Winter, M. Inst. C.E., was deputed by the Government to submit a design for suitable vessels to navigate shallow waters, such as the River Ganges in the dry season. He accordingly designed the steamers "Tay," "Spey," "Teviot" and "Tweed," with numerous large flats or troop barges, to the order of the Government of India. All these vessels were constructed by Messrs. Laird and Company of Birkenhead, sent out in sections and put together at the Government dockyard, Calcutta. One of the peculiarities of Mr. Winter's design was the spoon-shaped form of the bow, a form similar to that of most of the native boats. The three essential conditions of strength, light draught, and fair carrying capacity, were very successfully carried out, and they were undoubtedly admirably suited for the requirements of the Government, namely, the conveyance of troops and stores. The engines were of the ordinary horizontal jet condensing type, with radial paddle-wheels. They were fitted with an auxiliary engine for driving the air-pumps, so as to admit of the main engines being worked as high-pressure engines in case the vessel ran aground.

Mr. John Bourne, late Engineer for the Oriental Inland Company, also designed a fleet of powerful steamers and flats for service on the Ganges. These vessels were arranged to work as a continuous train, one steamer towing a number of cargo barges. The barges had no entrances nor runs, but having convex bows and concave sterns, the bow of one entered the stern of another, and formed a long vertebrated vessel. The idea was no doubt good, but it was impracticable, because, on the downward journey with the stream, when the vessels took the ground, as they frequently did, the whole train became disarranged, and the plan had to be abandoned. The Author has no doubt that, on a river offering no impediments to navigation, the idea could be carried out; but for river navigation in India experience has proved that the safest plan is to lash the barges alongside the steamer; steady progress is then made, and if, in grounding, the hawsers should part, no damage is done, and the flats can be at once reconnected. This is now the universal practice both in India and in Burmah.

At the present day there is not a river or canal of any importance in India but is supplied with steamers or launches of some description, either managed by the Local Governments or the public, and engaged in opening and developing trade and affording rapid and sure means of transit from trade centres. It is, however,

surprising to see the large numbers of native craft still profitably employed, and although the India General Steam-Navigation and Rivers Steam-Navigation Companies possess large fleets of steamers and flats, and carry a great portion of the produce through the districts traversed by their lines, there yet would appear room for more steamers to cope with the river-borne trade of the country now shipped by country craft.

As previously stated, Mr. T. B. Winter very successfully carried out the designs for a steamer, to work on shallow rivers, fulfilling the conditions of strength and power as well as moderate carrying capacity at a light draught. With vessels of this description the navigation of the Ganges as far as Revelgunge would be a profitable undertaking. It must always be borne in mind that all classes of vessels for river service must be built of sufficient strength to withstand the rough usage to which they are likely to be subjected.

The Author has appended a set of drawings and specifications, &c., of the three last steamers added to the fleet of the India General Steam-Navigation Company, namely, the "Varuna," "Indra," and "Rama," the last of which was constructed by Messrs. Burn and Company of Howrah. The vessels were designed either for despatch service, conveyance of passengers, the coolie trade of Assam, cargo, or towage of cargo flats. The "Varuna" and "Indra" were constructed at the Company's dockyard, Calcutta, at a cost of Rs.280,000 each, or about £19,000 sterling. The following are the principal dimensions:—Length over all, 262 feet 6 inches; extreme beam, 35 feet; depth at side, 10 feet; displacement at 5 feet, 840 tons; area of midship section at 5 feet, 169 square feet; area of load-water section at 5 feet, 6,950 square feet; displacement at 4 feet 6 inches, 744 tons 10 cwt.; machinery, boilers and water, 296 tons 19 cwt.; hull, stores and equipment, 336 tons 11 cwt.; coals, 111 tons, or 3,027 maunds. There is a capacity for 95 tons 10 cwt. of cargo at a draught of 5 feet.

The hulls are of steel, supplied by the Steel Company of Scotland, and are fitted with a longitudinal central bulkhead, extending from No. 1 collision to No. 6 cross bulk-head aft. There are seven cross bulk-heads, and further strength is secured by running a lattice-girder for 152 feet amidships; as also two side-girders (each 87 feet), between the upper and lower decks. The vessels have accommodation for five hundred coolies and twenty first-class passengers. On the fore part of the upper deck are placed the staterooms, lavatories, and saloon fitted with every comfort and convenience for the use of the passengers. The officers are provided

with cabins on the fore part of the sponsons, and the after sponsons are occupied with cooking gallies, hen-coops, and coolie latrines. The fittings for the conveyance of coolies have to be provided under the Government Emigration Act, and the vessels are finally passed for the Assam coolie trade by the Government Emigration Agent. They are provided with steam steering-gear and steam windlasses, as also hand capstans to assist in heaving off the vessel when aground. The roof is covered with corrugated iron, and under the corrugated iron is fitted bamboo trellis-work, over which are laid durmah mats to keep the coolie deck cool.

The engines consist of two sets of independent compound surface-condensing diagonal engines, and feathering-wheels supplied by Messrs. Denny and Company. The slide-valve arrangement is Brock's patent. The high-pressure cylinders are 28 inches, and the low-pressure 50 inches in diameter, with a stroke of 60 inches. Steam, at 100 lbs. pressure per square inch, is supplied by four steel boilers, 12 feet $5\frac{13}{16}$ inches in diameter, and 10 feet $1\frac{1}{8}$ inch long. The total heating-surface is 5,458·8, and the grate surface 202 square feet. Each boiler weighs 22 tons, and contains 14 tons of water. The engines and boilers were designed to indicate 1,200 HP., and were expected to drive the vessel at a speed of 15 miles an hour. On trial 1,396 indicated HP. was developed, and a speed of 15·4 miles an hour attained; the consumption of coal per indicated HP. was 2 lbs. The engines are models of lightness and strength combined, and the weight per indicated HP. is 476·4 lbs., a good result when the extra large boilers, and the fact of each set of engines being independent, is taken into consideration. Messrs. Denny and Company have given this important subject very great care.

The first of the type, the "Varuna," was commenced on the 18th of March, 1888, and was launched on the 26th of July, 1888. Every frame and plate was bent, fitted as required, and riveted at the Company's yard, from the raw material. All the work in connection with the construction of the two vessels, and placing of engines and boilers on board, was carried out entirely by native workmen, under the supervision of the Company's European assistants, in a highly satisfactory manner. The "Varuna" was completed in every respect, ready for service, in two hundred and twenty-six days.

The Author would remark, in conclusion, that his experience as an engineer, after twenty-eight years' residence in India, has greatly impressed him with the necessity for using large boilers in steam-vessels built for service in that country. The heat of the climate,

the bad coal, and the indifferent stoking combined, make it absolutely necessary that the boiler-power should be larger, in proportion to the size of the engine, than would be required when these unfavourable conditions have not to be contended against. The furnace and combustion-chambers should be as large as can be got into the boiler; the funnels should be of a considerable height, in order to ensure a good draught; the funnel-area about $\frac{1}{4}$ that of the grate, and the heating-surface not less than from 4 to $4\frac{1}{2}$ square feet per indicated HP. With these proportions a good economical result may be confidently expected.

The Paper is accompanied by seven tracings, from which Plate 7 has been prepared, giving details of line drawing, Figs. 1; general arrangement, Figs. 2; midship section, Figs. 3; side girders and bulk-heads, Figs. 4; "Chopper," Figs. 5; engine, Figs. 6; boiler, Figs. 7.

[APPENDIX.

APPENDIX.

SPECIFICATION FOR HULL.

General construction of proposed steel steamer. Length, 262½ feet; beam, 35 feet; depth at centre, 10 feet 9 inches to top of deck beams.

One longitudinal central and seven transverse bulk-heads riveted to skin of vessel. Top sides of vessel for about 87 feet amidships to be carried up to upper or coolie deck.

Longitudinal bulk-head to extend from collision bulk-head forward to bulk-head No. 7 aft, dividing the vessel in two portions. To be made water-tight, and carried from skin of vessel at keel-plate to above line of deck, forming one continuous line of plating, composed: bottom, $\frac{5}{16}$ inch; top, $\frac{5}{16}$ inch; and centre perpendicular plates, ¼ inch. The upper portion of longitudinal lattice-girder is to be formed of two 2½ inches by 2½ inches by $\frac{5}{16}$ inch angles riveted to a plate 9 inches by $\frac{5}{16}$ inch, and covered with a rider plate 9 inches by $\frac{5}{16}$ inch, and 6 inches angle-lug fastenings riveted to each upper deck beam, and from this plate for about 138 feet are to be secured angle-bar attachments 2½ inches by 2½ inches by ¼ inch. Plating of transverse bulk-heads, bottom, ¼ inch, and sides $\frac{3}{16}$ inch; remainder, ⅛ inch, stiffened with 2 inches by 2 inches by ¼ inch angles.

Keel-plate, for 30 feet long at ends, to be ¼ inch; remainder, $\frac{5}{16}$ inch. Skin plating between engine bulk-heads, ¼ inch; throughout bilge and sheer-strakes, ¼ inch; remainder, $\frac{3}{16}$ inch. Covering-plate at centre of vessel for 150 feet, ¼ inch; remainder, $\frac{3}{16}$ inch. Frames spaced throughout, 2 feet 6 inches, 3½ inches by 2½ inches by $\frac{5}{16}$ inch. Main-deck beams, one on every frame, 4 inches by 2½ inches by $\frac{5}{16}$ inch.

Upper-deck beams spaced 2 feet 6 inches, 3½ inches by 2¼ inches by ¼ inch.

Camber of both decks, 9 inches. Floors spaced 2 feet 6 inches throughout by 10 inches deep by ¼ inch thick.

Reverse angle-bars, 2¼ inches by 2¼ inches by ¼ inch, in engine and boiler-space to be riveted on both sides of the floors; remainder throughout, 2 inches by 2 inches by ¼ inch on one side only.

All reverse frames to be carried well up turn of bilge. Cants at sides to support upper-deck beams, 3½ inches by 2¼ inches by ¼ inch.

One intercostal keelson to be placed on either side of longitudinal bulk-head, continuing for about 180 feet amidships, finishing off at the ends of the vessel with two angles back to back secured to reverse frames of floor, angles, 2½ inches by 2½ inches by ¼ inch; intercostal plating, 12½ inches by ¼ inch. Nine of the 10-inch floors in centre of engines on either side of the vessel continued up sides to under side of deck. Covering-plate with the reverse angles to be continued upon edge of plates. Two intercostal shelf-pieces 12 inches wide, angle-bars outside riveted to sides of vessel for a distance of 40 feet, and spaced 3 feet 9 inches.

Every third frame, for about 170 feet amidships, to be carried up on each side of longitudinal bulk-head to meet deck beams, and riveted through bulk-head.

Gusset-knees on every deck beam, both at longitudinal bulk-head and ship-side, for the whole length of the central longitudinal bulk-head; and diagonal angles between each frame riveted one to either side of bulk-head.

On upper side of bilge-strake are to be two angles back to back, secured with angle-lugs, riveted to each frame of the vessel. Angles, 2½ inches by 2½ inches by 5/16 inch; gussets, 12 inches by ½ inch; stem and stern-posts, 6 inches by 1 inch; top deck stanchions on every second frame.

Main deck to be of teak, 6 inches by 2½ inches, in lengths not less than 20 feet.

Upper deck to be of teak, 6 inches by 1½ inch, in lengths not less than 20 feet.

A. J. Bolton,
Superintendent Engineer, I. G. S. N. Co., Limited.

Calcutta, 21*st June*, 1889.

General Specification for four Boilers.

Specification for four marine multitubular steel boilers for two sets of engines to indicate 1,200 HP.

Four marine multitubular steel boilers to Board of Trade requirements for a working pressure of 100 lbs. per square inch. Each boiler 12 feet 5 13/16 inches diameter, to contain two of Fox's corrugated furnaces, 3 feet 9 inches mean diameter, with one combustion-chamber common to both furnaces; width across combustion-chamber to be 30 inches. Diameter of tubes, 3½ inches outside. No. 8 B. W. G. by 7 feet, spaced 4¾ inches centre to centre, in vertical rows. Total heating-surface not less than 5,400 square feet.

Boilers to fit in the space as shown in drawing, leaving room for stoking, and each boiler to have one funnel not less than 3 feet 7 inches diameter, and 40 feet above firebars. Funnels to be hinged where marked on sketch. Boilers to be fitted with McNeil's patent man- and mud-hole doors. Smoke-boxes and doors. Uptakes and air-casings. Firebars in two lengths. Fire-bearers. Dampers for funnel and ash-pit. Boilers to be fitted with Dewrance's gauge-columns and test-cocks, with all necessary pipes and cocks for attachments to boilers. Blow-off, scum and other cocks. Patent spring safety-valves with casing gear, and one spare spring. Complete working drawings of boilers, showing seatings required to clear butts and seams. Boilers and all works to be of the best materials and workmanship, and made under the supervision of the Board of Trade, and to be tested by water to a pressure of 200 lbs. per square inch.

The four boilers, each 12 feet 5 13/16 inches diameter, complete with uptakes, funnels, &c., &c., must not exceed 90 tons in weight. Actual weight of boilers complete to be forwarded as early as possible.

General Specification for two sets of Engines.

Specification for two sets of paddle diagonal surface-condensing compound engines, for the India General Steam Navigation Company, Limited, to indicate 1,200 HP.

Two sets of compound surface-condensing, feathering, paddle-engines, complete in every detail, ready for working, to include the usual spare gear, as per Board of Trade list—savealls, spanners, eye-and-hook bolts, sets of taps and dies, complete sets of engine-room telegraphs, indicators and indicator-gear complete for taking diagrams.

Type, diagonal compound, constructed for a working pressure of 100 lbs. per square inch, and piston speed not less than 400 feet per minute, and 1,200 indicated HP. Slide-valves, arranged and adjusted so that high- and low-pressure cylinders shall indicate the same power, equalising twisting strain on both engine-cranks. All bearings, connecting-rods, top and bottom ends, and main bearings, to have extra large surfaces. Main bearings may be run with best white metal over brass. Connecting-rod top and bottom and guide brasses should be of phosphor bronze. Each set of engines supplied with Dewrance's or other good make, sight feed-lubricators, in addition to all other necessary oil-cups and cocks requisite for lubricating purposes, fixed in their respective positions.

All parts of the engines that may require overhauling and adjusting from time to time must be arranged to be easy of access.

Air- and circulating-pumps placed vertically; surface condensers to have ample tube-cooling surface adapted for a sea temperature of 90°, and to maintain abundant feed-supply, irrespective of the auxiliary feed. Condensers placed athwartship, arranged with necessary appliances for working either common jet or bilge injection. Condensers, before being placed on board, must be tested to 30 lbs. per square inch; all necessary air-vessels, air-pipes, relief-valves, &c., to be fitted. Circulating inlet at the bottom, and outlet on the top, of condenser. Engines so placed to admit of space to draw condenser tubes.

Feed- and bilge-pumps of sufficient capacity with all necessary air-vessels—relief-spring, test-cocks, &c., to be supplied.

High-pressure cylinder, 28 inches in diameter; low-pressure, 50 inches in diameter. High-pressure cylinder fitted with single-ported, and the low-pressure with a double-ported valve, all ports and passages, induction and eduction, to be of large areas. Cylinders not jacketed, but very carefully felted and lagged with best Honduras mahogany, neatly secured with brass-polished stout hoops securely fastened with screws to barrels of cylinders. All necessary escape-valves, guards, and cocks to be fitted.

Stroke of engine, 60 inches.

All shafting, piston- and other rods, to be of the best quality of steel, supplied by one of the most approved manufacturers in the United Kingdom, who make shafting a speciality.

Each set of engines supplied with steam reversing-gear, so arranged that in case of need the engines can be quickly manipulated by hand, and all gear necessary for working the engines should be conveniently brought together on the engine platform, so as to be easily handled by one man.

All necessary sea-cocks and valves on skin of vessel to be supplied of the most modern design. All necessary copper and other piping, faucets, bends, elbows, &c., &c., required for the various connections from high-pressure cylinder to boiler's stop-valves, to be supplied. Also feed- and bilge-pumps, ash pipes, exhaust and discharge pipes, &c., with all cocks and valves necessary to enable the engines to work under steam when placed on board the ship in Calcutta.

Main steam-pipe between boilers to be overhead, with connections to high-pressure cylinders.

Two good powerful donkey-engines, capable of supplying four 12 feet $5\frac{13}{16}$ inches diameter boilers with abundance of feed, against a working pressure of 100 lbs. per square inch, and, in addition, arranged to work on deck as fire-engines.

A good hand-pump for filling boilers to be fitted; compound vacuum and steam-gauges of best make required for each engine.

Paddle-wheels to be of the most modern type as regards design of feathering and other gear. Diameter at centre of axis of floats, 15 feet; number of floats

on each wheel, eight; size of each float, 12 feet by 3 feet; total area of float surface, 576 square feet. All bushes of gun-metal, all pins of steel, bushes bored, and pins, &c., turned. The scantlings of wheels to be strong. All bolt-holes rimered, and bolts carefully fitted. Wheels carefully and well put together.

All work as regards engines, piping and wheels, must be of the highest-class workmanship and finish, and well painted. To be carefully marked for erection on board the vessel in Calcutta, well and carefully packed, and contents of each package noted in invoice. Each set of engines to be of different colours. Engines to be constructed as light as possible consistent with ample strength. Tracing supplied showing sheer draught plan of steamer, and space available for engines and boilers. Height of centre of shaft, 10 feet 10 inches from bottom of vessel. Speed of vessel, 15 miles per hour. Successful contractors will submit as early as possible their arrangement for engine and boiler seatings, which must be made of as light materials as possible.

Position of all sea-cocks on skin of vessel to be carefully marked. Time of delivery in Calcutta to be stated. Engines and boilers placed so that vessel will float on an even keel.

Omissions: Any omission in this specification so far as regards the requirements of engines, and all connections from the engines, as well as from engines to boilers, will not be regarded as an omission, as it must be distinctly understood that the contractor has to deliver the machinery in Calcutta complete in each and every detail, ready, when placed on board the ship, to raise steam.

Engines and paddle-wheels, complete for service, must not exceed 150 tons in weight. Actual weight of engines complete to be forwarded as early as practicable.

A. J. Bolton,
Superintendent Engineer.

21*st June*, 1889.

Note.—400 feet piston speed is given to show what strains the engines should be designed to stand in conjunction with the 100 lbs. pressure per square inch. —A. J. B.

OBITUARY.

JOHN PERCY, third son of Mr. Henry Percy, was born at Nottingham on the 23rd of April, 1817. He received his early education from the Reverend Charles Fletcher, of Southwell, in Nottinghamshire, under whose guidance the inclination of his mind in the direction of chemical and physical studies, which soon became apparent, was carefully and systematically trained. Between 1834 and 1836 he studied in Paris, where he came more particularly under the influence of Gay Lussac, Chevreul, and Thenard, the great teachers of physics and chemistry of the day. Subsequently he proceeded to the University of Edinburgh, where he devoted himself to medical studies, and graduated M.D. in 1839, receiving a gold medal for a thesis on the detection of alcohol in the brain, in cases of alcoholic poisoning, which was subsequently published. He also received a medal for proficiency in botany, and a third for general merit. After the close of his academical career, he settled down to medical practice in Birmingham, and became physician to the Queen's Hospital in that city, where he attained to considerable professional eminence, having, in addition to the ordinary duties of his office, carried out some elaborate pathological researches, the value of which was recognized by his election to the Fellowship of the Royal Society in 1847. Other researches in mineral and metallurgical chemistry were not, however, less actively pursued, and during his residence in Birmingham Dr. Percy was largely engaged in the study of the properties of nickel, manganese, and other allied metals, and contributed in no small degree to the foundation of the modern method of nickel and cobalt extraction, whereby these metals are obtained of any desired degree of purity. He also made the experiments on the use of sodium hyposulphite for silver extraction, which process was afterwards applied on the large scale by the late Bergrath von Patera, in Bohemia; and in subsequent modifications, by Russell and others, is now becoming a formidable rival to amalgamation as a means of treating refractory silver ores in the Western States of America. The effects of phosphorus upon copper formed another subject of his early investigation, and subsequently a method of refining founded upon his experiments was practically developed at Chatham Dockyard by

his pupil and assistant, Mr. William Weston, now the chemist to the Admiralty.

In 1851, upon the foundation of the Royal School of Mines, by the late Sir H. T. DelaBeche, Dr. Percy accepted the position of lecturer upon metallurgy, and Metallurgist to the Museum of Practical Geology, which offices he retained until 1879, having given up medical practice on leaving Birmingham. During these years he delivered a long course of lectures yearly, besides superintending a large teaching laboratory, and a smaller advanced one devoted to research purposes; and in one form or another, either as pupils or assistants, most of the metallurgical chemists who have risen to eminence since 1851 came under his influence. The first important work undertaken in his private laboratory was the systematic analysis of the collection of the iron ores of Great Britain, made for the Great Exhibition of 1851, by the late Mr. S. H. Blackwell, who contributed a sum of £500 for the expenses, which amount was largely supplemented by Dr. Percy, the work having employed for several years a succession of chemists, including Messrs. R. Smith, E. Riley, Allan Dick, John Spiller, Charles Tookey, and W. J. Ward. The results were afterwards published in the Memoirs of the Geological Survey, but no part of the cost, except that of fuel and water in the laboratory, was met from public funds. Large numbers of original experiments for the illustration of his volumes on metallurgy were also carried out both by his regular assistants and by several of his old students. Among the results obtained in this way were the discovery of the method of producing aluminium from cryolite, and the alloys known as aluminium bronzes, and the relation between the composition of the pig-iron used and the metal obtained in the Bessemer process. Very extensive researches were also carried out for the War Office committee on iron armour-plates, and subsequently for the Admiralty committee on steam-boiler corrosion. Doctor Percy also served on the Royal Commission on Coal in the United Kingdom, and on that on Spontaneous Combustion in coal-laden ships. He was also a member of the Royal Commission on the Ordnance Store Department, presided over by Sir James Stephen, whose report was published in 1888.

Upon the death of the late Dr. D. B. Reid, he was appointed superintendent of ventilation to the Houses of Parliament, and on the foundation of the department of advanced artillery studies at Woolwich, now the Artillery College, he became lecturer on metallurgy, which offices he held until his death.

The greater part of his life was, however, devoted to the pro-

duction of his great systematic treatise on metallurgy, of which five volumes appeared at intervals between 1861 and 1880, and which, though incomplete, remains a remarkable monument to his genius and industry. The volume on iron and steel is, after twenty-five years, still in demand, as, although in great part obsolete as regards processes in use, it possesses a high value as a magazine of historical information, and as a record of original research.

A new edition of this volume was in course of preparation, and it is believed that a considerable portion has been left nearly ready for publication. This work earned for its author the award of the Howard Prize in 1887, which was expended at his request upon a microscope equipped under Dr. H. C. Sorby's direction, with all necessary appliances for the study of the micro-crystalline structure of metals, to be placed, under the direction of the Council, at the disposal of members of the Institution desirous of undertaking researches of this kind, in which he felt great interest. In 1863 he was appointed by the Trustees of the British Museum to the Swiney Lectureship in Geology, and during his four years' tenure of office he delivered a systematic course of lectures on chemical geology, which did much to popularize the study of a subject which at that time received very little attention from English geologists.

Dr. Percy was a keen student of photography in the earlier days of the collodion processes, and was one of the founders of the Photographic Society, having served as a Vice-President in 1857. He rendered important services in this connection as a member of the committee on fixing and toning prints, whose report may be said to have formed the basis of photographic practice up to a comparatively recent date. He was an artist of very considerable ability, and for many years was in the habit of going on sketching tours with artist friends, particularly with the late Mr. C. Landseer, R.A., and Mr. E. W. Cooke, R.A. His knowledge of English water-colour art was very great, and his collection illustrating its history is one of the most complete in existence.

Dr. Percy was elected an Honorary Member of the Institution on the 14th of May, 1872, and of the Iron and Steel Institute in 1875. He received the Bessemer Medal of the latter body in 1876, and served as President in 1885–86. The meetings during his term of office were of exceptional interest, no small part of which was due to the original and suggestive addresses delivered at each successive occasion from the chair. After the close of his presidential term, Dr. Percy's health gradually failed, and he was

unable to attend the opening meeting of this Institution in November 1887, on the occasion of the award of the Howard Prize. Although confined to his house for nearly two years, no symptoms of any immediate danger were apparent until the commencement of June, 1889, when he was seized with an alarming attack of cardiac inflammation, which, though not immediately fatal, prostrated him so completely, that he never rallied again, and passed away quietly on the 28th of that month, being then in his 73rd year. Although very weak, he retained full command of his faculties to within a very short time of his death, and was thus enabled to learn that the Council of the Society of Arts had awarded him the Albert Gold Medal, the highest honour in its gift, and the announcement was made public in a very feeling notice in the Journal of the Society, which appeared on the day of his death.

WILLIAM CHRISTOPHER BENNETT, eldest son of Ignatius Bennett, of Rathmines, co. Dublin, was born on the 4th of July, 1824. He was articled to Mr. P. Griffin, who was then managing the completion of the boundary survey of Ireland, under Mr. (afterwards Sir Richard) Griffith, Bart. Mr. Bennett was employed on territorial and railway surveys for local works and measurement of artificers' works until the year 1845. At this period he was employed in the field on the survey of the proposed line of railway from Limerick to Belfast, the longest line at that time projected in Ireland; and was charged with the preparation of the plans at the office in Dublin.

Early in 1846, he entered the service of the Irish Board of Works in the Drainage Commission, and was employed on surveys and works of the Kenman Talka and Inmy districts; but in 1847 he was transferred to Mayo, when he took charge of the Castlebar and other lakes in the Mullafarry and Balla districts, under Mr. Frederick Barry, and executed some very important works in a highly satisfactory manner, eliciting on several occasions the warm approval of Colonel (afterwards Sir H. D.) Jones, with Mr. Commissioner Mulvany, who remarked in a jocular way when inspecting the works,—"You will be a Commissioner, Mr. Bennett, yourself some day." And his prediction has been fulfilled.

Mr. Barry, his chief, to whose great kindness he always attributed his advances in life, at this time became a warm friend; and on one occasion, for several months Mr. Bennett acted as District Engineer, in charge of all the drainage works in Mayo, having

four or five thousand men under him when only twenty-two years of age. On the completion of the drainage works in Mayo, he was offered by Sir C. Fox, through Messrs. Lionel Gisborne and H. C. Forde, an appointment to proceed to New Grenada to report on the navigation of the Magdalena River, and on its connection with the sea at Savanilla and Cartagena, where a canal had been made by Colonel G. M. Totten, Chief Engineer of the Panama Railroad. Mr. Bennett had also to report on the best means of connecting the head of the navigation with the capital Bogotá. On this service, he was assisted by Captain Ellis, of the Royal Navy, and performed the duty in a manner which gave great satisfaction. Before proceeding to South America, he visited France, and passed some time on the Rhone and Saône, so as to make himself acquainted with the mode of navigating these rivers, the boats upon which were at that time some of the largest in the world.

On his return to England from South America, he was engaged, in conjunction with Mr. Gisborne, in the preparation of plans for a proposed embankment of the Thames, preserving all the rights of the frontages. This project did not, however, go further than the depositing of the plans; at the completion of which, he went to assist Mr. Barry with his plans of the Northern and Western railways of Ireland.

At the end of 1853 Mr. Bennett again sailed with his friends, Messrs. Gisborne and Forde, for the Isthmus of Darien. While there he had charge of the surveys on the Pacific side, Mr. Forde having to remain at Panama owing to a serious illness. Mr. Bennett executed fully all the surveys and explorations entrusted to him, surveying and levelling by himself a large tract of country towards the Chuqunaque River; having no companion through that hostile country but black chainmen. He also assisted to bury some men belonging to H.M.S. "Virago," under the command of Captain (now Admiral) Prevost, who were shot by the Indians while he was there; and afterwards accompanied Lieutenant Forsyth in the boat of the "Virago," up the Chuqunaque River for the rescue of Lieutenant Strain, of the United States Navy, and his missing party, in which they succeeded; and for this service, Mr. Bennett received the thanks of the American Government through the Secretary of the United States Navy. He was the last man of the expedition to leave the Isthmus, but he suffered in health from exposure to the climate. After a few months' rest, Mr. Bennett determined on breaking new ground at the Antipodes, and left England for New Zealand in 1854,

where he made only a short stay, but had the experience of an earthquake which took place at Wellington in January 1855. He then determined to return to England, *viâ* Sydney; but, on calling on Sir Thomas L. Mitchell, then Surveyor-General there, he was induced by that gentleman to enter the survey department of New South Wales, with the view of ultimately obtaining employment on the public works of the Colony. On the death of Sir Thomas, about nine months after Mr. Bennett's engagement, he left the survey department, having been appointed Assistant City Engineer under Mr. Edward Bell, which position he held with that officer until December 1856, when the Sydney Municipal Council Bill was passed, which abolished the offices of the three commissioners under whom the control of the city had been previously placed. In 1857 he obtained an appointment under Mr. John Whitton, the Engineer-in-Chief for Railways in New South Wales; and was placed in charge of the Campbelltown railway extension, where he remained until 1858, when he was selected by Captain (afterwards Colonel) Martindale, R.E., then Commissioner for Internal Communication, to superintend the repair of a large bridge at Bathurst, which had been injured by floods. Captain Martindale was so pleased at the manner in which this work was completed that he offered to recommend Mr. Bennett for the position of Engineer to the Roads Department, and he was appointed to this office (just created) from the 1st of January, 1859. He remained in this office until 1861, when he resigned with his chief, Captain Martindale; though, at that time, he was offered the commissionership of roads by the Hon. W. M. Arnold, M.L.A., then Minister for Public Works. Mr. Bennett's intention was to proceed to India, where he had long wished to go; but on his arrival in England, he found that he was beyond the age fixed for official appointments. He therefore arranged to return to Sydney, where he arrived in February 1862, after an absence of only twelve months. After a short engagement, again under Mr. Whitton, in the Railway Department, he received the appointment of Commissioner and Chief Engineer to the Roads Department, which he retained until his retirement from the public service on a pension from the 1st of July, 1889.

On the 6th of June, 1868, in addition to his other onerous duties, he became an additional member of a Commission appointed on the 24th of September, 1867, "to inquire into the provision for a supply of water to the city of Sydney and suburbs." An elaborate report was made and presented to Parliament, recommending the adoption of a scheme, the first suggestion of which was made by Mr. Bennett, for bringing the water from

the Cataract River, on the surface of the country; but this proposal was modified and improved on by Mr. Moriarty.

In April, 1869, he was appointed to serve on a commission "to inquire into and report respecting floods in the district of the Hunter River"; and also acted on commissions "to report on the management and supply of water to the western goldfields," and "upon the adoption of a narrow-gauge railway to Mudgee." The latter commission, chiefly at his instance, reported against any break of gauge, preferring to recommend the completion of the macadamization of the 80 miles of road, which was carried out and completed within two years by the Roads Department. Many other important works of water-supply, wells and tanks on long lines of road in the interior were carried out under his supervision. Up to the end of 1888, the total length of main roads, metalled and gravelled, was nearly 6,000 miles, in addition to nearly 4,000 miles of unmetalled roads; and about 40 miles of bridges had been constructed, many of them the largest in the southern hemisphere.

Mr. Bennett was for some time a member of the Royal Society of New South Wales, and for two years acted as a member of its Council. He carried out and completed, shortly before his death, the grand scheme for the main sewerage of the city of Sydney and eastern suburbs, now in operation; and for nearly two years, just prior to his retiring from the Government service, he acted as a member of the Board of Sewerage and Water Supply, which department was established principally upon his suggestion and recommendation. He was a most conscientious and upright man, an energetic worker, a strict disciplinarian in his department, and fearless and impartial in the administration of his public duties.

About the month of March he had an illness, caused by failure of action of the heart, when his medical adviser urged him to give up the heavy duties he was performing; but being desirous of seeing the completion of some important works then in hand, he continued on until the month of June, at which date he became so seriously ill that he sent in his resignation, and retired on his well-earned and ample pension, while the Government, in recognition of his able services in carrying out the city and suburban sewerage works, submitted to Parliament a vote on the Supplementary Estimates for 1888 of £2,700, as a gratuity for the supervision of this gigantic work, which was readily granted. Unfortunately, he did not long survive these advantages, and from the date of his retirement was scarcely able to leave his bed. His death took place on the 29th of September, 1889.

Being of a genial disposition, and possessing the inestimable quality of friendship, he has left many true friends to remember him, while his works will stand for generations as monuments of his ability and great labour.

To Mr. Bennett is generally accorded the reputation of being one of the ablest engineers in Australia. A former colleague writes:—

"Our late chief, Mr. W. C. Bennett, . . . was a man of singular ability, prodigious energy, and untiring industry. Having been associated with him for the last nine-and-twenty years I can testify to his worth . . . The immense department which has grown up under Mr. Bennett's control, and the work it has done, will probably not be chronicled till it, like he, has broken down under the strain, increasing as it does from year to year. Both have done their work nobly and well; both deserve the honour not always accorded where most merited."

Mr. Bennett was elected an Associate of the Institution on the 19th of May, 1857, and was transferred to the class of Members on the 16th of February, 1864.

ARTHUR ROBERT WILLIAM FULTON, a son of Mr. J. Fulton, M.H.R. for Taieri, New Zealand, was born, at Otago, in that colony on the 3rd of October, 1853. After spending some time at a private school, he became a student of the Dunedin High School, and in October, 1873, entered the government service, on a term of four years, as a cadet in the New Zealand Public Works Department under Mr. John Carruthers. As a mechanical draftsman, showing great ability, he quickly attracted the attention of his superior officers. When the Government undertook the construction of railways on the west coast of the South Island, Mr. Fulton was employed under Mr. C. Y. O'Connor, the engineer in charge of the works successively, on 20 miles of the Napier and Waipukuran Railway, on a similar length of the Westport and Ngakawau Railway, and the Buller Harbour Works. On the expiry of his cadetship, he passed the examination as an authorized surveyor, and then was engaged as an assistant engineer, chiefly on the Picton and Blenheim Railway. In 1878 he became assistant to Mr. H. P. Higginson, under whom he was engaged as Resident Engineer during the construction of the Waimea Plains Railway, the Kawarau Suspension Bridge, the Balclutha Bridge, and various other works and surveys for works. In July, 1881, Mr. Fulton entered the service of the New South Wales Government, and was engaged on the survey for the Goulburn and Cooma Railway, but less than a year later he returned to New

Zealand to take up the position of Resident Engineer on the Southern Section, 36 miles in length, of the Wellington and Manawatu Railway, New Zealand, to which he had been appointed on the recommendation of Mr. Higginson, the Chief Engineer. On the completion of this railway (84 miles in all), Mr. Fulton had entire charge of the line, having been also appointed traffic manager. He proved himself specially able in the work, being a clever organizer as well as possessing much above the average standard of ability in engineering acquirements. His late chief and old friend, Mr. Higginson, writes, "I had the very highest opinion of his abilities and judgment, and consider that we have lost the brightest example of an engineer, who had received his education and training entirely in the Colony. Having been intimately connected with Mr. Fulton for the last sixteen years, I consider that I am perhaps the best able to speak as to his character and abilities, and I can assure you that his death is a loss to this Colony, where he would inevitably have made his mark before long."

Mr. Fulton was elected an Associate Member on the 4th of February, 1879, and was transferred to the class of Members on the 20th of November, 1888. He died on the 26th of July, 1889.

RICHARD THOMAS HALL was born on the 31st of May, 1823. In 1839 he was articled for five years to his uncle, Mr. Richard Thomas, engineer of the Hayle Railway, and sub-engineer of the western portion of the proposed London, Salisbury, Exeter and Falmouth railway of 1836. On the expiration of his pupilage in 1844, Mr. Hall was employed by Mr. Joseph Locke, Past President Inst. C.E., on surveys in Devonshire and Cornwall, and four years later he was appointed engineer of the Redruth and Chasewater mineral railway, a position he retained, with the additional office of general superintendent, for twenty years. In 1868, the Cape Copper-Mining Company engaged Mr. Hall to survey and construct a railway between their mines at O'okiep and Port Nolloth, with a jetty at the latter place, the railway being about 90 miles in length. He remained in charge of the work till March, 1875, when he accepted the appointment of railway engineer to the South African Republic, and in this capacity superintended the extremely difficult work of surveying the proposed railway from Pretoria to Delagoa Bay. When, two years later, the Transvaal became British territory Mr. Hall's office was abolished, and he proceeded to Cape Town in June, 1878, to take up the position of

Maintenance Engineer of the North Eastern line of railway, to which he had been appointed by Government. He was detached on temporary duty for a few months in 1879 and 1880 on survey work, being placed in charge of a staff surveying proposed lines in the Eastern Province from Queenstown to Aliwal North, Burgersdorp, and Dordrecht, and that work being completed, Mr. Hall resumed his post on the North Eastern Railway in 1884; he was transferred to the Eastern system also as Maintenance Engineer, and continued to hold that position till he retired from the Government service, on pension, in 1886. Later on Mr. Hall became Manager of the Thomas Gold Mining Company. In 1889 he was appointed to take charge, as Chief Engineer, of the railways of the Orange Free State, and was on his way to headquarters when he died, at Johannesburg, on the 21st of August, after an illness of only four days.

Mr. Hall was elected an Associate of the Institution on the 3rd of December, 1872, and was transferred to the class of Member on the 9th of January, 1883. He was in all respects a valuable public servant, and his death is generally regretted at the Cape, where his kindness of heart and courteous demeanour towards all with whom he came in contact had caused him to be universally respected.

HAMILTON LEE-SMITH was born on Christmas Day, 1829, at Edinburgh, where his father, the Rev. George Smith, was a leading minister of the Established Church of Scotland.

About the year 1846 Mr. Lee-Smith was articled to Mr. George Turnbull, who was then engineer of the London end of the Great Northern Railway, at that time under construction. The subject of this notice was engaged on the works of the Copenhagen Tunnel, and is said to have been equal to any amount of long-continued hard work, and was very careful and exact in what he had to do.

On the completion of his pupilage he became an Assistant Engineer on the same line, and held the post for two years. In 1851 Mr. Turnbull was appointed Chief Engineer of the East Indian Railway, and proceeded to organize his staff. He offered Lee-Smith a position as Assistant, and on the 20th of April, 1852, the latter sailed for India in company with his chief. On his arrival he was sent to the Raneegunge branch to assist Mr. Edward Purser, a former fellow-assistant on Mr. Turnbull's Great Northern Railway staff. Two years later Mr. Purser was posted as Chief to the North-

Western Provinces, and gave Mr. Lee-Smith the Agra district, of the railway of which he became the Resident Engineer, and so remained till the end of 1864. In 1865 Mr. Lee-Smith entered the service of the Government of India, and was appointed to lay out the Lahore and Peshawur Railway. This line, subsequently known as the Punjab Northern State Railway, was destined to become the subject of much bitter controversy. When the Government first proposed its construction, the late Mr. Samuel Power, who had succeeded Mr. Turnbull as Chief Engineer in Bengal of the East Indian Line, was asked to reconnoitre the suggested alignment. This he had only time to do cursorily, and at his recommendation Mr. Lee-Smith was nominated to make the survey and prepare the plans, being subsequently made Engineer-in-Chief by the Secretary of State for India. Mr. Lee-Smith joined the staff (which had preceded him) at Lahore in December, 1868, and was immediately engaged in preparing the surveys and sections for the line between Jhelum and Rawal Pindi. It was decided by the Government that the line between Lahore and Jhelum, with the exception of a short distance out of the Lahore station of the then "Delhi Railway" down to the crossing of the River Ravee, and a short deviation through the Kharian Gap, should be constructed on one half of the Grand Trunk Road. On the completion of their field-work Mr. Lee-Smith removed his staff to Murree for the hot season, and there had plans, sections, and estimates worked out, and prepared three designs for the Ravee Bridge; but the Government were undecided in selecting from these plans, and in February, 1869, Mr. Lee-Smith returned to England, and on arrival was employed at the India Office perfecting the design which was eventually adopted, and in inspecting the manufacture of the bridge by Messrs. Westwood and Baillie. The railway was originally intended to be constructed on the standard Indian gauge of 5 feet 6 inches. The proposed substitution of the metre gauge met with Mr. Lee-Smith's determined opposition, and led to his resignation in 1872. An indirect consequence of this was the memorable controversy within the walls of the Institution, recorded in vol. xxxv. of the Minutes of Proceedings. In the course of a discussion, which occupied seven meetings, Mr. Lee-Smith defended the standard gauge so effectually that it was eventually adopted. The high principle which had induced Mr. Lee-Smith to take up this position and, regardless of his own interests, maintain it successfully in the face of the most vehement antagonism of the officials of the Indian Government, was typical of his character, which was most fearless and independent.

Early in the year 1878 Mr. Lee-Smith was appointed Chief Engineer of the Egyptian railways with headquarters at Cairo. Here he had entire control of a network of lines aggregating 1,200 miles in length. During his tenure of office he did much to improve the general condition of the way and works, and his services were recognized by the Khedive, who conferred upon him the 3rd Class of the Medjidieh, himself investing the recipient with the insignia of the order. Mr. Lee-Smith resigned this appointment in 1881. He had become deeply interested in the fortunes of the country, and, after the conclusion of the war in 1882, associated himself with others in the attempt to form a company for the construction of a railway from Suakim to Berber. In this he had almost succeeded when the outbreak of the Soudan Rebellion put a stop to the operations. This railway, had it been made at the time, would probably have saved double its cost in the futile expedition to Khartoum, and the almost periodical reliefs of Suakim.

In June, 1888, Mr. Lee-Smith was sent out by the Honduras Company, in command of an expedition, to make a verification-survey of certain parts of the old route, located by Trautwine and others, for an interoceanic railway. Here, as elsewhere, Mr. Lee-Smith made a very good impression, as was evinced by the President of Honduras presenting him with a handsome gold watch and chain. He spared no pains in endeavouring to fulfil what he considered to be his duty to the Honduras Company, although the work was of the most arduous nature, the whole route from the Atlantic to the Pacific Coast being over rough ground, covered with tropical vegetation, interspersed with stretches of swamp reeking with miasmatic exhalations. However, Mr. Lee-Smith managed to get through with his party, returning to London about six months after leaving it. But the work killed him. He reached home in an exhausted state, though by dint of exerting the most determined will-power he managed to write his report, and, helped by his devoted assistant, Mr. J. Robins, prepared an approximate estimate of the cost of constructing a railway from Port Cortez on the Atlantic to Amapola on the Pacific. Then, after some months of intense sufferings uncomplainingly borne, he took to his bed, dying of heart disease on the 3rd of September, 1889, in his sixtieth year.

Mr. Lee-Smith was elected a member of the Institution on the 3rd of December, 1861.

In his varied career he had not unfrequent occasion to differ from others connected with the works in hand. This arose in no

way from any over-estimate of his own ability, nor from any incapacity of working smoothly with those around him, for few men were more heartily genial and sympathetic, and ready to take suggestions into fair consideration; but he was eminently an enthusiast, and would struggle to the last in favour of what he had arrived at as the fit thing: witness his action in the question of changing the gauge of the Punjab Northern State Railway. His pleasant, manly bearing and genial temper made him extremely popular all around, whether in business or socially.

JAMES ROBERTSON, the son of a Scotch farmer, was born at Blair Athol, Perthshire, on the 16th of February 1818. He was educated at the High School at Perth. At the age of fifteen he entered the office of the late Mr. Alexander Mitchell, then practising as an engineer and surveyor at Perth, where he acquired the first rudiments of his profession.

At this time the late Mr. Joseph Mitchell, who had been appointed Government Engineer for the construction and opening out of new public roads through the north of Scotland, having seen young Robertson at his brother's office, offered to take him as a pupil, and accordingly in 1834, when sixteen years of age, he entered that eminent engineer's service. In a country where the rivers were large and numerous, where trickling mountain streams were liable to become fierce and swollen torrents in a few hours, and where the contour of the land was rugged in the extreme, the difficulties of road construction were naturally very formidable. Into this work young Robertson entered with indomitable energy and perseverance, and soon became noted for the care and accuracy with which he carried out any work entrusted to him, as well as for the skill and neatness he displayed as a draughtsman.

In 1838 he became connected with his first piece of railway work, being appointed, at the age of twenty, assistant to the Resident Engineer, the late Mr. Thomas Telford Mitchell, to supervise the construction of the Slamannan Railway from Coatbridge to Manuel, now forming part of the North British system, the late Sir John Macneill being the Engineer-in-Chief, and during that time he was also engaged on the survey for the extension to Boness on the Firth of Forth.

When the Slamannan Railway was completed, at the end of 1840,

Mr. Robertson obtained a situation in the Mining Estate Office at Dudley; he found, however, that, contrary to his expectation, his work lay chiefly underground, which, in addition to being distasteful to one who had hitherto passed a more than usually free and open life on his native mountains, affected his health, and he therefore decided to abandon it at once and try his fortune in London. His father, who was in easy circumstances, hearing of his intention and the state of his health, wanted him to return home, but Mr. Robertson was of too enterprising a nature to do that, and accordingly to London he went in May 1841, knowing no one there and with only slender means at his command.

He was obliged to content himself with a situation as one of the assistants to the Superintendent in the outdoor department of the Locomotive Works of the London and South Western Railway Company at Nine Elms, which placed him in a sphere of occupation, less genial to his taste than he had been brought up in. He remained there for three-and-a-half years, acquiring a very practical insight into the construction, working, and management of locomotive engines and other rolling stock, an experience which he often said was of the greatest value to him afterwards, when holding responsible positions in the working of railways.

In the Autumn of 1844, the late Mr. Joseph Locke, M.P., Past President Inst. C.E., found himself burdened with an unusually heavy parliamentary session, and in need of more assistants to help in the preparation of the surveys and plans to be lodged that year. He therefore applied to Mr. John V. Gooch, the Locomotive Superintendent of the London and South Western Railway, to lend him any one in his service who could be of use on such work. Among those selected was Mr. Robertson, and so satisfied was Mr. Locke with the way in which he carried out his work, that after the deposits for that year had been made, he kept Mr. Robertson engaged on other matters, and shortly afterwards took him on his staff.

In March 1845, owing to his recent mechanical training, Mr. Locke sent Mr. Robertson to Ireland to examine and report on the working of the Atmospheric Railway between Dublin and Kingstown, and later on he used frequently to watch the experiments and working of the London and Croydon Atmospheric line. Attention was given to this system, because in the memorable contests which took place between the Great Western and South Western Companies for the Devon and Cornish traffic, Mr. Brunel proposed to work some at least of his lines on the atmospheric principle, and Mr. Locke held that this system would be a failure.

Under Mr. Locke's guidance, Mr. Robertson soon developed the talent he possessed for selecting the best routes for railways through new country, and was constantly employed on the numerous projects that emanated from the office of his chief. In 1845, he laid out the London and South Essex Railway (55 miles), starting from Bow on the Blackwall Railway, and terminating at the mouth of the River Crouch on the East Coast, with branches to Tilbury and Southend, but this line was rejected by the House of Lords on the assumption that there was not enough traffic in the district to warrant its construction. As a somewhat curious incident it may be mentioned that he lived to see, forty years afterwards, extensions of the Great Eastern Railway, and the London, Tilbury and Southend Railway carried through very much the same district he had formerly advocated. He was also engaged this year in the laying out of the Romsey and Redbridge Railway, the Basingstoke and Salisbury Railway, the widening of the Blackwall Railway Viaduct, and assisted in the completion of the survey for the Winchester, Southampton and Poole Railway. He also investigated the method to be adopted for passing the proposed London and South Essex Railway traffic over the Blackwall line, at that time worked by ropes and stationary engines.

In the early part of 1846, he was directed by Mr. Locke to lay out the Exeter, Yeovil and Dorchester Railway, and he finally made a deposit of that line, which, with its branches to Sidmouth, Chard, Bridport, &c., represented a total of 93 miles. The fight over this line (Session 1847) was one of the celebrated contests of the olden time. The Great Western and the South Western Companies each deposited schemes, in November 1846, from the neighbourhood of Yeovil to Exeter with branches to various places. The Great Western Railway had as leading counsel the celebrated Talbot and Serjeant Wrangham, while Mr. Cockburn (afterwards Sir Alexander Cockburn, Lord Chief Justice of England) appeared for the South Western. The closing speech of the latter lasted six days.

Victory rested with the South Western Company, and their opponents' bill was thrown out. There was no time to carry the Bill through both Houses that year, and with others it was specially carried forward to 1848, when it finally passed. In the sequel, the powers obtained were suffered to lapse, in the bad times which followed the railway mania.

Other projects and surveys, on which Mr. Robertson was engaged in 1846, were the Cornwall and Devon Central Railway, the South Western and Oxford Junction Railway, from Overton

through Newbury to Didcot, the Epsom and Staines Railway, and the Guildford and Portsmouth Railway. In 1847, in addition to looking after the schemes already in hand, some of the fresh works he was employed on were the Epsom branch of the South Western Railway, the Exeter and Cowley Bridge Railway, the Godalming and Chichester Railway, and the London and Oxford Railway, which was a bold scheme in opposition to the Great Western, for a line from the South Western system near Brentford, passing through Hanwell, Uxbridge, High Wycombe and Thame. He was also engaged on the London Bridge Extension, a proposal of the South Western to build a station close to the River Thames, near the Borough Market; upon Poole Station enlargements, the Southampton Dock Extension Railway, the Portsmouth and Fareham deviations; and he had the privilege of assisting in collecting and preparing particulars for Mr. Locke's evidence, and Mr. Brunel's cross-examination in the famous controversy on the question of Gauge.

Other projects which passed through his hands later were the Padiham Branch of the East Lancashire Railway, the Metropolitan Extension of the South Western Railway, the Godalming Extension, the Weymouth Branch, and the Royston and Hitchin Deviations. During these years he was constantly giving evidence before Parliamentary Committees.

In 1848, Mr. Locke was called in to advise the Directors of the East Lancashire Railway, who had fallen into a dispute with their contractors, in which an outlay of over a quarter of a million was involved, and he sent Mr. Robertson to report upon the condition of the line, and then deputed to him the task of measuring up and valuing the whole work. Some idea of the amount of labour this required will be realized from the fact, that the arbitration was not concluded till five years afterwards, and that the examination of Mr. Robertson, who had then left Mr. Locke's service, lasted six days. The following year he went as Resident Engineer to expedite the works on the Farnham and Alton, and the Guildford and Godalming lines, and when they were opened, to supervise the completion of the Aberdeen Railway, then in course of construction, undertaking the measuring up and settlement of the accounts with the various contractors, which in some cases were a matter of arbitration. He was also engaged at this time in laying out the Deeside Railway, for which he gave evidence before Parliament.

At this time the mania for making railways had ceased, and Mr. Robertson, not seeing much prospect of further demand for the services of his profession, determined to turn his attention to the

supervision of lines that were at work. In April 1851, at the age of thirty-three, he obtained the post of General Manager and Secretary, on the Glasgow, Paisley and Greenock Railway. Thus ended his career with Mr. Locke—a chief for whom he entertained the greatest admiration and respect; nothing gave him greater pleasure in the closing years of his life than to be present at the annual dinner at which Messrs. Locke and Errington's old assistants meet, and with his associates there recall the memory of the happiest and most interesting period of his life.

The Greenock line was in good order, paying a small dividend, and could have been much improved had not the imminent prospect of its amalgamation with the Caledonian Railway prevented the directors spending more than was absolutely necessary on it; and when, hardly more than six months after his appointment, this arrangement was actually accomplished, his occupation as Manager died out, and he remained as Secretary only, with no scope to carry out any improvements or enterprises. This was no employment for a man of his ability and energy, and he never rested until, in November 1852, he obtained the appointment of Manager to the Edinburgh, Perth and Dundee Railway Company, in succession to Mr. Archibald Scott, who had left it in order to join the London and South Western Railway Company. On his retirement he received a vote of thanks from the Directors of the Greenock Railway, for the way in which he had conducted the settlement with the Caledonian Railway, and the ability displayed in safeguarding their interests.

The Company with whom Mr. Robertson now found himself was in a very bad financial condition at this time, the line, from its position joining no important place north or south, except by the two ferries of the Forth and Tay, being a hopeless one to work successfully as an independent concern. However, into this new sphere of action Mr. Robertson threw himself with indomitable will and energy, and had the satisfaction, in February 1856, of seeing his labours rewarded by the company declaring its first dividend. In addition to the onerous task of conducting the policy and superintending both the passenger and goods traffic, for some considerable time he also carried out the duties of engineer, looking after the permanent way, engines, harbours, dockyards, workshops and steamers belonging to the Company, where he encountered so very lively an experience in the maintenance of the ferry-boats, that he always regarded steamboat traffic afterwards as a very expensive source of revenue, producing anything but satisfactory returns.

The tremendous competition between the various companies in England and Scotland, for the traffic passing between the two countries, had become at this time so ruinous to all, that in 1855 the first serious attempt was made to come to some agreement between them as to the proportion each should receive. A large general meeting of directors and managers was held at the Railway Clearing House in London, on the 20th of March, 1855, which resolved, "That in the opinion of this meeting the time has arrived when it would be expedient to endeavour to effect a settlement of all the traffic comprehended in the Sextuple and Octuple agreements, and otherwise between England and Scotland," and a committee of eight general managers called afterwards "the Octuple Committee" were appointed to try and carry that resolution into effect. Mr. Robertson was one of those chosen, and at this distant date it is interesting to learn that his colleagues were Captain Huish, of the London and North Western (Chairman of the Committee), Mr. Robert Sinclair, of the Caledonian, Mr. Seymour Clarke, of the Great Northern, Captain O'Brien, of the North Eastern, Mr. (now Sir James) Allport, of the Midland, Mr. Latham, of the Edinburgh and Glasgow, and Scottish Central Companies, and Mr. Stirling representing all the lines north of the Tay. This committee met for the first time on the 11th of April, 1855, and after holding eighteen meetings was able to report, on the 6th of July, that its labours had been so far successful, that it had come to the resolution of reporting to the Boards of the respective Companies concerned the progress made. Judged by the light of time this view would appear to have been somewhat sanguine, as even now it would be hard to say that the questions at issue are finally settled. But to Mr. Robertson, and those associated with him, belongs the credit of having laid the foundation of the arrangements upon which this complicated matter has been from time to time adjusted and solidified.

It was inevitable that the Edinburgh, Perth and Dundee Company should be amalgamated with some of the larger companies near it, and therefore most dispiriting was the management of a line placed in such a defective position; nevertheless Mr. Robertson kept working away in his steady fashion, making some progress but not enough, from the nature of the case, to satisfy an earnest man longing heartily for a more congenial post. In 1856 a quasi amalgamation came with the Scottish Central and the Edinburgh and Glasgow Railways, in the shape of a working agreement, and his appointment became void. Mr. Robertson's directors were loth to lose him, but the preponderating influence

of the larger companies carried the appointment and their own manager with it, and the only thing that remained was to pass a resolution of the Board to that effect, bearing testimony also to their unanimous approval and appreciation of the way Mr. Robertson had fulfilled his duties during his term of office.

At the suggestion of his old superintendent Mr. John V. Gooch, then at the Locomotive Works at Stratford, Mr. Robertson was induced to apply in February 1856, at the age of thirty-eight, for the position of Superintendent of the out-door and passenger traffic on the Eastern Counties Railway, with which were included the Northern and Eastern, the Norfolk, the East Anglian, the Newmarket and Eastern Union Railways. About this time he also made an application for the post of Superintendent on the Great Western Railway, carrying the negotiations so far as to have an interview with Mr. Saunders, then Secretary of the Company. However, on the 2nd of April, 1856, he was appointed by the Directors of the Eastern Counties Railway, of whom Mr. David Waddington, M.P., was at that time Chairman, to the situation he had applied for, which he retained up to the time of his death, a period of thirty-three and a half years.

He had now entered on a field where there was unbounded scope to bring into play all the resources that his varied experience could command, as well as all the energy and ability he so largely possessed. He came to the railway when its future looked well nigh hopeless and blank, when each of the several companies interested in it had their own board of directors with local interests of course paramount; unenviable indeed was the notoriety it possessed for accidents, unpunctuality and the accommodation it afforded its passengers in the shape of carriages and stations; in fact it is hardly too much to say that it was a by-word for all that was uncomfortable and disagreeable in railway travelling. To put an end to this discreditable state of affairs, to place the working of the traffic on a sound and efficient basis, and to restore to the line the confidence of the public was the herculean task that Mr. Robertson set himself to perform, and right well and ably did he accomplish it. He was among the first to appreciate the benefits to be derived from the use of the block system, and the interlocking of points and signals, giving the most careful and painstaking attention to bring the development of those ideas to a practical issue, a work involving the greatest care and responsibility to ensure that his company should be advised as to the best and most reliable means to be employed. He was one of the witnesses called before the Committee of the House of Lords appointed, in 1873, to

inquire into the Regulation of Railways, with a view to the prevention of accidents, of which the Duke of Somerset was Chairman, when he was able to state that the Great Eastern Railway had been one of the first Companies to introduce those systems twelve years previously in 1861.

In 1862 the various lines in the eastern counties became amalgamated under the title of the Great Eastern Railway, Mr. Horatio Love being the first Chairman; and henceforth the results of the good order introduced by Mr. Robertson began to appear in the improvement of the working, and more especially in the immunity of the line from accidents, for, in drawing up a report for the Directors in December 1873, he could say that for eight years, from 1864 to 1871, no passenger was killed from causes beyond his own control on the line, in 1872 only one, and in 1873 again not one. That such an eminently satisfactory result should have been obtained, speaks volumes for the way in which Mr. Robertson had imbued all around him with his own spirit of discipline, regularity and earnestness of purpose. No more satisfactory climax to these labours could have been afforded than the reading to him, barely twenty-four hours before his death, of the statement which had appeared in *The Times* newspaper a few days previously, asserting on good authority that in the matter of punctuality the Great Eastern Railway stood first and foremost of any line in the country.

Shortly after the amalgamation, the Great Eastern Railway Directors embarked, under the guidance of Mr. Robert Sinclair as Engineer, upon the scheme for their metropolitan extensions, and the removal of their terminus from Bishopsgate to Liverpool Street, that gentleman being succeeded by the late Mr. Edward Wilson, to whom it fell to carry out these large and important works. Mr. Robertson's former experience as a civil engineer now became of the greatest assistance, and the plans for the construction of any part of the line affecting the traffic, such as the arrangement of station buildings and yards, the accommodation to be provided for passengers and goods, and the laying out of all junctions, had in every case to receive his assent and signature before they could be carried out. The whole arrangement of the lines, sidings, platforms, booking-offices, &c., of the Liverpool Street terminus, perhaps the busiest station in London, and certainly one of the most difficult to master, were all carefully considered and put into working order by him, with a measure of success which no one, as he averred, unacquainted with the requirements of a civil engineer's training could possibly have achieved; but entailing

such a vast amount of extra work as to quite affect his health at the time. In the same manner he also took part in the construction of the Great Northern and Great Eastern joint lines from March to Doncaster.

To the signalling, throughout the whole line, he gave the most assiduous care, his arrangements for difficult junctions and yards having called forth special commendation from the Government Inspector on more than one occasion. He always considered it the most important element in the safe working of the traffic, would allow no one to share the responsibility with him, and was most careful in his selection of signalmen.

In March, 1865, he was offered by Mr. Seymour Clarke, then General Manager of the Great Northern Railway, the post of Superintendent of that line, but Mr. Robertson's Directors, recognizing the value of his services, acknowledged them in such a substantial way as left him no inducement to leave the work he was so engrossed in, and by that time had so thoroughly mastered.

To Mr. Robertson's manner of dealing with the men may, perhaps, be attributed the success which attended his tenure of office. He had the faculty of gaining the affection as well as the respect of every one he came in contact with, and there was hardly a man on his own staff, and they numbered in late years about eight thousand, who was not inclined to credit his chief with some mark of personal kindness.

At the meetings of Superintendents at the railway clearing-house, Mr. Robertson's opinion was always listened to with the greatest deference and attention, as coming from one who spoke with large experience and sound judgment. He played a considerable part in preparing the revised and improved code for the public and private working of railways issued by the special committee of Superintendents, appointed at a general conference, of which he was one.

Mr. Robertson was elected a Member of the Institution on the 5th of December, 1854, and a Fellow of the Royal Scottish Society of Arts in the same year. He was a captain in the 8th Essex Volunteers from 1859 to 1864.

Mr. Robertson was well known to H.R.H. the Prince of Wales, having made all the arrangements in connection with the royal visits to Sandringham from their commencement, and he had the honour of being invited on several occasions to garden-parties at Marlborough House. The Prince wrote from Athens when he heard of Mr. Robertson's death, deeply regretting the circumstance, and directing that his condolence should be sent to the family.

An excellent constitution enabled Mr. Robertson to attend without remission to his duties almost to the end of his life. The illness which terminated in his death, on the 7th of October 1889, lasted only ten weeks, and he can fairly be said to have died in harness at the age of seventy-one. Perhaps no higher tribute can be paid to his memory than the injunction given to a meeting of the official staff of the Great Eastern Railway by the Chairman, who ended an allusion to Mr. Robertson's career among them by saying, "Go thou and do likewise."

GEORGE WILSON STEVENSON was born at Derby on the 10th of April, 1825. He became a pupil of Mr. Hawksley, at Nottingham at the age of seventeen, and remained with that gentleman until the expiration of his articles. In 1847, Mr. Stevenson went to the United States, but returned to England within two years. He was soon appointed Surveyor to the Local Board of Loughborough, from which he retired to enter into partnership with Mr. William Lee, an Inspector under the Public Health Act. During this partnership he carried out several sewerage and water schemes. In 1856, he received the appointment of Borough Engineer to the Corporation of Halifax. He had almost at once to advise the Corporation in reference to the proposed purchase of the gas undertaking. The parliamentary fight was very keen, and the manner in which Mr. Stevenson bore himself under the severe cross-examination at once brought him forward as an expert witness. The Halifax gas-works, which were on the side of a steep hill, had to be entirely rebuilt, and great skill was shown in constructing the buildings upon the slope of the hill, so that the coal was brought in at the highest point, and the coke taken out at the lowest point of the works with a minimum of handling. Throughout the ten years of his residence in Halifax, Mr. Stevenson was largely consulted by Companies and local authorities in reference to gas and water undertakings, until he was compelled by increase of business to remove to London in 1866, since which date, until within a year of his death, he was in constant practice as consulting engineer for gas, water, and sewerage matters. He published in 1879 a book on "Precedents in Private Bill Legislation affecting Gas and Water Undertakings." He designed new gas-works for West Bromwich, Scarborough, Colchester, Peterborough, and several

other places, and in all carried out in their entirety, or partially, some sixty works or systems for gas, water, or sewerage.

Mr. Stevenson was elected an Associate of the Institution on the 1st of April, 1851, and was transferred to the class of Members on the 27th of May, 1879. He was President of the Gas Institute in 1882.

Mr. Stevenson died on the 23rd of October, 1889.

WILLIAM STROUDLEY was born on the 6th of March, 1833, at Sandford, in Oxfordshire; in 1847 he was apprenticed to Mr. John Inshaw, of Birmingham, but as his parents were not able to pay a premium he got no indentures. He worked in the shop, learning to fit and turn, and to work the engines in a twin-screw passenger boat started in 1840 by Mr. Inshaw, to run on the canal between Birmingham and Wolverhampton. In 1848 he went for a few months to work an engine of 15 HP. for Mr. Middleton of the Vulcan Foundry, Birmingham, and then performed similar duties for Mr. W. Dean, an engineer and millwright, in Birmingham, under whom he acquired practice as a hand-turner and at general work. He was also sent out to assist in the erection of a set of pumps and a steam-engine to drain a deep well at the Hatton Asylum, near Warwick. In 1849 Mr. Inshaw received an order for the engines of eight steam-boats, on his plan of twin-screws, for the Grand Canal Company, Dublin, and Mr. Stroudley was again engaged with him, being employed fitting up the engines and boilers, after which he was sent to Dublin to assist in erecting them; this and other work kept him employed until 1851, when he went to work for Mr. Edwards, of the Islington Foundry, Birmingham; there he was engaged in erecting a large condensing engine for a corn-mill, and afterwards on a pair of compound engines for a paper-mill, and another pair of compound engines for Messrs. Nettlefold and Chamberlain, Birmingham. By this time he was near twenty years of age, and Mr. Inshaw failing in business, young Stroudley left him, and in May 1853 was engaged at the Swindon Locomotive Works, where he was employed, under the superintendent, the late Sir Daniel Gooch, in fitting up valve- and slide-motions for new goods-engines. He was principally engaged on piece-work, at which he occasionally earned as much as 7*s.* per day. He was soon advanced to day-work at 31*s.* 6*d.* per week. He received an offer from his old

employer, Mr. Inshaw, in the early part of 1854, to go out to Australia to erect a pair of engines and a corn-mill; and Stroudley left Swindon for that purpose, having been offered £15 per month; on reaching home, however, his parents used every means, and successfully, to persuade him not to leave England. In consequence he went to the Peterborough shops of the Great Northern Railway, and started to work as a running-shed fitter under Mr. Owen, the District Superintendent. In September 1854 Mr. C. Sacré succeeded Mr. Owen, and on his becoming acquainted with Stroudley he made him working foreman, and he had charge of the passenger-engines at Peterborough, doing all ordinary repairs, at a salary of £104 per annum. In 1857 he was sent by Mr. Sacré to take charge of a small line of railway for Lord Willoughby D'Eresby, which had failed from bad management. He worked this line, 5 miles long, having gradients of 1 in 40, 1 in 30, and, in one part a long incline of 1 in 27, and got the permanent way put in good order, improving the switches and crossings, so that the line was passed for passenger-traffic by Colonel Yolland, and gradually settled down to an ordinary branch line. In 1858 Mr. Stroudley was induced by his brother, who was Manager of the Helpstone Paper-mills, to-take charge of the steam-engines and machinery at that place, as they were in very bad order; and on the Managing Director offering him £2 10*s.* per week, with house, &c., he agreed to do so, and soon made great alterations in the machinery and the consumption of coal. He got everything into excellent order, and in 1859 went back to his old post at Peterborough, where he had charge, as before, of the passenger-engines, but under Mr. Francis Cortazzi, Mr. Sacré having been appointed to the Manchester, Sheffield and Lincolnshire Railway. In less than a year Mr. Cortazzi was appointed Locomotive Superintendent of the Great Indian Peninsula Railway, and Mr. W. Brown succeeded him at Peterborough and New England. Mr. Stroudley continued to give the most unremitting attention to his duties, and was able to keep the passenger-engines at Peterborough in excellent order, and their consumption of coke and coal at the bottom of the list. The Peterborough district included Grantham, and the passenger-engines collectively ran about 20,000 miles per week.

In September 1861 Mr. Brown was appointed Locomotive and Carriage Superintendent of the Edinburgh and Glasgow Railway; and in October of the same year Mr. Stroudley was made Manager of the Cowlairs Works of that railway at Glasgow. He had entire charge of repairing and building locomotive-engines, carriages and

wagons, and of the large stationary engine and rope for working the Glasgow Junction. He had also charge of designing the engines, carriages, and wagons, the Drawing Office likewise being under his superintendence. During this time there were built about fifteen new engines, eight new boilers for the stationary engines, sixty cariages, and four hundred wagons; besides many heavy repairs of all kinds were effected. He turned up the large pulleys, 20 feet in diameter, of the incline engine; put in the new boilers (which he had both designed and made in the shops), and also inserted heavy girders under the main shaft plummer-block; the whole of this work was done without causing the least stoppage or delay to the engines, although they only stood still for twelve hours on Sunday. For this work Mr. Stroudley was congratulated by the Members of the Institution of Mechanical Engineers, on their visiting the works on the occasion of their meeting at Glasgow.

Mr. Stroudley also designed and built a small engine for a steam-yacht, and was successful in producing the fastest and lightest boat on the Clyde. The boat was built by Mr. William Denny, of Dumbarton, and he paid Mr. Stroudley the compliment of saying it was the best small engine and boiler he had ever seen. The boat was 35 feet by 5 feet, and would run 11 miles an hour. His salary as Manager of the Cowlairs Works was £200 per annum, with free house, coals, &c., and Mr. Brown having bad health, he had more than his share of the charge of the work.

In 1865 Mr. Stroudley was appointed Locomotive and Carriage Superintendent at Inverness of the Highland Railway, at a salary of £500 per annum. During his stay at Inverness he designed snow-ploughs, which have been successful in keeping that line clear and open for traffic ever since. He also designed new workshops, which were accounted at the time among the simplest and most convenient in this country. He invented and patented a locking-apparatus for facing points, as also a "ramp" for re-railing carriages, wagons, or engines, which is in use on almost all the railways in Great Britain, on the Continent, and in India.

In January 1870 he was appointed to the position of Locomotive and Carriage Superintendent of the London, Brighton and South Coast Railway, where he had the entire charge of the locomotive and carriage department and of the engines, machinery, &c., of the Company's sea-going steamers. On the 24th of May in the same year he was elected an Associate of this Institution; and on the 6th of February, 1877, he was made a full Member.

During the twenty years that Mr. Stroudley held the position of

Locomotive Superintendent to the Brighton Railway, he succeeded in raising himself to the very front rank of English mechanical engineers. His early career was such that he had no opportunity of obtaining what is termed technical education. Professors of engineering never taught him anything; in a letter accompanying his application for admission into the Institution, he said, with proud humility: "I am the son of a working-man, and have been a working-man myself." His mathematical attainments were of the most moderate description; and yet it may be doubted if that which Mr. Stroudley did not know was, for the engineer, worth knowing. Above and beyond most men, he possessed a special power of not only doing the right thing in mechanical engineering, but of doing it in the right way. He wanted to know the reason for everything, and was always ready to give a reason for what he did. He continually and persistently went to the roots of things, and from these he worked upwards. For instance, he found that on the Brighton Railway, as on others, carriage- and wagon-axles broke constantly. They always broke at the same place—the junction of the journal with the wheel. He cast about till he found the reason. Then he eliminated the cause, and as a result, to all intents and purposes, broken axles disappeared. His early experience with locomotives showed him that the paramount defect of such engines is being short of steam. Given steam enough, and almost every other defect becomes endurable. Consequently, he adopted what may be termed lavish proportions for his boilers, and the result was one which he never regretted. A lesson once taught him by experience, he never forgot; it was stowed away in a stupendous memory, and acted upon when the occasion arose. Thus, for example, a fireman was killed while standing on the tender by his head coming in contact with an overhead bridge. Mr. Stroudley resolved that this class of accident should become impossible in the future. A man may now stand where he pleases on the tank, his head will clear a bridge by a foot. He found that the wheels of the tenders were different in diameter from those of the engines, and he asked himself if there was a good reason for this; finding that there was not, he designed all his engines with carrying-wheels of the same diameter as those of the tenders. The axles and journals are the same, and thus they are all interchangeable. He inquired why coupled engines should have the outside cranks radially opposite to the inside cranks. The answer was that they then balanced each other; but he also saw that the stresses in the driving axle-boxes were very much augmented; so he put the coupling cranks at the same side of the centre as the inside cranks,

and forged suitable balance-weights inside the wheels. The results were all that he expected.

Now and then he adopted experimentally things about whose success he had doubts, but he always so managed that the evil consequences of failure should be minimised. Showing to a friend certain long bogie passenger-coaches, he explained that they had been built in deference to the wishes of others in authority. "I am not quite sure whether they will suit our lines," he said, "but they are just twice as long as our ordinary stock, and if they don't answer I'll put a hand-saw through them, and so make two bodies out of one."

Mr. Stroudley had an intense and truly refined sense of mechanical fitness. On him a faulty, ill-designed, or unmeaning detail had the same effect as a discord on a musician, and he valued good workmanship next to good design. He carried his views on this point almost to an extreme. He would never tolerate the least leak about a locomotive; and it is scarcely too much to say that no one can tell by looking at one of his engines, standing, whether it is in steam or not, unless the safety-valves happen to be blowing off. He invented many things, but his skill and talent were more fully manifest in what is known as "scheming" than in inventing. He would take sheet after sheet of drawings, and give a definite reason why each separate detail was made as he had made it, and not in some other way or of some other shape. It was quite possible that the listener did not agree with him; that might be a matter of opinion, but there could be no doubt of the honest sincerity of purpose which prevented him from ever adopting any shape or form, or proportion, or thing, because it "would do well enough." Nothing did "well enough" for Mr. Stroudley. He manifested wonderful powers of selecting the best of several solutions of a difficulty—not only the best mechanically, but the best and most suitable all round. He was always ready to adopt and acknowledge what was good. Thus, for example, being satisfied that the Westinghouse brake was the best for his purpose, he introduced it on the Brighton line, modifying it where necessary. In steamships he accepted the compound system as the best possible, but he would not use it for locomotives. He did not reject it blindly or without reason. He maintained persistently that there were circumstances and conditions under which it would do good service, but that these did not exist on the lines under his control. He believed that a big boiler would always give as good results with a non-compound engine, as could be got with a smaller

boiler out of a compound engine; and he pointed to his coal-bills, asking if any locomotive superintendent could beat them.

In his management of men, Mr. Stroudley was a rigid disciplinarian, but extremely fair-minded and just. He delighted in giving men an interest in their work, and adopted many devices for the purpose. He held that there was no reason why a locomotive or its driver should be dirty, and the foot-plates of the Brighton Railway engines have been fastidiously kept under his rule.

Mr. Stroudley was among the earliest to recognize the value of the system of interchangeability of parts, and to carry out that system to its full extent in his own practice. Not only did he make engines of the same class identical in all respects, but he also made many of the parts of engines of different classes interchangeable. As he had but few types of locomotives, he thus built up a workshop system of great simplicity; he was rigorous in the application of the principle, preferring to sacrifice a part which accidentally differed from the standard, rather than admit any deviation from his rules. In the management of his men it was his aim to cultivate in them the same pride in their work which he felt himself; each driver had his own engine, and his name was painted inside the cab, with the number of miles run between successive overhauls. In this way a spirit of emulation was set up, and the extra care which the machinery received far more than compensated, in Mr. Stroudley's opinion, for the reduced amount of work which any one engine was able to perform, in consequence of its being in charge of one set of men only.

One of the most striking points in Mr. Stroudley's practice was the use of large leading-wheels. He ran express engines with 6 feet 6-inch coupled leading-wheels, a plan which greatly simplified the design, since it enabled him to utilize the weights of the cylinders and motion for adhesion, and to avoid the use of cast-iron foot-plates. The small trailing-wheels also allowed of the construction of a specially large firebox. The centre of gravity of the engine was kept high, and the outside rods were placed on the same side of the crank-shaft as the corresponding inside rods. Engines of this type have done splendid service on the Brighton line, and all who have ridden on them will willingly testify to their exceptionally steady running. Mr. Stroudley was strongly opposed to complication, and hence he kept to the six-wheel engine without bogie or radial axle, believing that for such a line as he had to work, the truest economy lay in the use of simple engines of moderate weight and ample heating-surface. His practice, which

embodied a great number of original and interesting features, has been fully recorded in the Paper on Locomotives, which he presented to the Institution in 1885, and for which he was awarded a Telford medal and premium.[1]

Mr. Stroudley had the knack of making friends among every class with which he came in contact, and even those against whom he was obliged, by business requirements, to act in opposition were impressed by his intelligence and individuality. He approached every question from an original standpoint, and was never content to follow an established usage unless it could be demonstrated to him that it was right. The most striking example of this feature of his character is found in the fine boats of the Brighton Railway Company which run between Newhaven and Dieppe. Mr. Stroudley was neither a naval architect nor a marine engineer, yet it is probable that all the best points both in the vessels and their engines were due to him. Many men in his position would have thrown the entire responsibility upon the builders, and would have accepted their designs without criticism. But so far from doing this, he not only got out the drawings for the engines, but also constructed models of various forms of hulls, making up for his lack of technical knowledge by ingeniously devised experiments, which enabled him to determine displacement, metacentric heights, and the like, without recourse to mathematics, or to the accumulated data possessed by shipbuilders. The results have more than justified his action, for the boats have not only been exceedingly successful, and economical in working, but they have been accepted as embodying the correct type for channel service.

Again, the peculiar circumstances of the Brighton Railway, which embraces a network of nearly 100 miles of suburban lines in the London district, with many steep inclines and frequent stations, and which lines have to be worked by frequent trains of moderate weight, induced Mr. Stroudley to depart entirely from the beaten track in designing an engine to suit this traffic. As a result he introduced little three-coupled tank locomotives which, probably from their small proportion and general all-round usefulness, came to be known as "Terrier" engines. Here, as in a goods engine, every particle of the weight is utilized for adhesion; and, as the "omnibus" service which the terriers work does not call for high speed, these machines are very economical, while their wheel-base being not much greater than that of the ordinary two-coupled engines, they are able to go round sharp curves with ease. Mr.

[1] Minutes of Proceedings Inst. C.E., vol. lxxxi. p. 86.

Stroudley got a gold medal for one of these engines, the "Brighton" at the Paris Exhibition of 1878; and it was in connection with another engine exhibited at Paris, in 1889, the "Edward Blount," for which again he got a gold medal, that he met with his death. This locomotive, named after the Chairman of the Western Railway of France, with which the Brighton Company has very intimate relations, embodied all Mr. Stroudley's most recent practice, and had attracted much notice at the Exhibition, both from its design and its splendid workmanship. In December 1889, Mr. Stroudley was summoned to Paris to conduct some trials with it on the Paris, Lyons and Mediterranean Railway, in competition with several other locomotives that had been in the Exhibition. While thus engaged he got a chill, which being neglected, rapidly induced inflammation of the lungs. He died in Paris on the 20th of December, 1889. The body was brought to Brighton, and four days later was interred in the extra-mural cemetery of that town, a funeral procession extending for more than ½ mile testifying to the opinion of William Stroudley entertained by the engineering world and by his fellow-townsmen.

ROBERT VAWSER, third son of the late Mr. Charles Vawser of Waldersea, March, Cambridgeshire, was born on the 13th of September, 1841, educated at Peterborough, and afterwards articled to the late Mr. M. O. Tarbotton, of Nottingham, with whom he subsequently remained for a short period, being entrusted by Mr. Tarbotton with the carrying out of various important works.

In 1863 Mr. Vawser entered the office of the late Mr. C. E. Cawley (sometime M.P. for Salford), of London and Manchester, under whom he designed and superintended various engineering works. In 1866, he left Mr. Cawley, having obtained the appointment of principal assistant to the Borough Engineer of Belfast, under whom he carried out public works of considerable magnitude, including the sewering and paving, in one year alone, of one hundred and thirty streets.

In 1867 Mr. Vawser was appointed Borough Surveyor of Warrington, where he designed and carried out many important works, including main-sewerage works, several miles of impervious pavements, an infectious disease hospital, art gallery, &c. In his letter of resignation, dated October 22, 1877, he stated that nearly ten years had elapsed since his pleasing association with the council commenced, and that he should always remember with

satisfaction that the Borough Surveyorship of Warrington was his first public appointment.

Mr. Vawser commenced business on his own account in Manchester, immediately after relinquishing his appointment at Warrington, and soon acquired a large and lucrative practice, more especially in sewerage and sewage works, and at the time of his death was engaged upon important works at Swinton, Milnrow, Reddish, Tyldesley, Royton, &c. He did not, however, devote himself exclusively to sanitary engineering, and amongst other works was engaged upon the extensive system of tramways, known as the Manchester, Bury, Rochdale and Oldham Tramways, the Barrow-in-Furness Tramways, &c.

Mr. Vawser took an active interest in the Association of Municipal and Sanitary Engineers and Surveyors, his connection with the Association dating from its formation, when he began his services as Honorary Secretary for the Lancashire and Cheshire District. In 1875 he became a Member of Council, in 1880 a Vice President, and in 1885 President. During his presidency the examinations of candidates for municipal engineerships were instituted. Mr. Vawser always evinced the keenest interest in the affairs of the Association, largely contributing to its proceedings, and his early death is deplored by the members generally.

Mr. Vawser was elected an Associate of this Institution on the 4th of April, 1871, and was transferred to the class of Members on the 26th of January, 1875.

His numerous engagements in this country did not, however, leave him many opportunities of attending the meetings of the Institution. He died, somewhat suddenly, on the 15th of September, 1889, after a long and painful illness.

WILLIAM MANN CROSLAND was born at Holbeck, Leeds, in 1824. Early manifesting a talent for engineering, he was in the year 1838 apprenticed to Messrs. Fenton and Murray, of Leeds, in whose factory he went through the usual routine of shops and drawing-office. In 1843 he was transferred to Messrs. Wren and Bennet, of Manchester, with whom he stayed until 1845, thus fulfilling the customary seven years. On completing his apprenticeship, Mr. Crosland entered the works of Messrs. Maudslay, Sons, and Field, of Lambeth, and with that eminent firm he passed the remainder of his professional life. His duties were to contrive,

adapt, and direct in the construction of marine and other engines. In this capacity he had to do with most of the large machinery turned out by the Lambeth firm during his connection therewith. Among the most notable work of the kind was the machinery for H.M.SS. "Valiant," "Agincourt," "Lord Warden," "Viper," "Sirius," and "Druid," the engines of the White Star Liner "Atlantic," and other vessels; also similar work for the West India Mail Packet Company, the Union Company Cape Packet, the Russian Steam Navigation Company, and the Brazilian and Chinese Governments. He was also concerned in making the great chain-cable proving machinery for Lloyd's, and the pumping machinery for the drainage of the tunnel proposed in 1868 to be made under the Indus at Attock, but which was abandoned in favour of a bridge. Mr. Crosland was entrusted with the construction of a replica of Brunel's block-making machinery for the Portuguese Government, and introduced some simple improvements that added greatly to the power of the machinery by obviating friction. Although by no means proficient in mathematical or theoretical science, Mr. Crosland was a practical engineer. His knowledge of machinery was extensive, and he was frequently consulted by sanguine inventors. Of these, it might be said, that if their hopes were often dashed by his honest and outspoken criticisms, their pockets were saved in like manner.

For some years before his death Mr. Crosland retired from active professional work, though he continued to take a keen interest in all matters relating to machinery. He was also attached from the first to the Volunteer movement, in which service he held the rank of Captain. He died on the 14th of October, 1889.

Mr. Crosland was elected an Associate on the 2nd of December, 1851, and on the divisions of that grade into the professional and non-professional classes, became an Associate Member.

JOHN REES GEORGE, the son of a London solicitor, was born at Lewisham, Kent, and, on leaving school, entered the office of a tea-merchant. He did not take kindly to commercial pursuits, and, having a taste for mechanical drawing, he was transferred to the office of Messrs. Kennard Brothers, contractors, of Great George Street, Westminster, in which firm one of his brothers was at that time occupying a good position. Here he made such rapid progress that, before he was twenty years of age, he was

sent to Spain to assist in the construction of the iron bridges on the Pamplona and Saragossa Railway over the rivers Ebro and Aragon. Thence he proceeded to Portugal where he remained for some years for Messrs. Kennard, and had charge of the construction of the Tagus Bridge on the Lisbon and Badajoz Railway; of various bridges on the Lisbon and Oporto Railway; and acted as assistant engineer of sewage and general construction of the Portuguese Railway. In this work he displayed, for one so young, extraordinary ability, and his employers, recognising his sterling worth and capacities, on his return to England, made him general manager of several important engineering works, among them the bridge on the Horsham and Guildford railway. Mr. George left London in 1865 as agent for the firm, with Mr. N. Marchant, as engineer, and commenced in Wellington, New Zealand, the extension works in connection with the Queen's Wharf. The next work undertaken by Mr. George was the superintendence of an iron bridge across the river at Wanganui. Then he laid down the patent slip at Evans Bay for the Patent Slip Company. In 1869 Mr. George began practice on his own account, and became engineer of the Wellington Gas Company, and, on the completion of the works, continued to act as general manager. He was also appointed engineer to the Wellington Slip Company, both of which posts he continued to hold until his death on the 26th of July, 1889.

Mr. George took considerable interest in local matters appertaining to the welfare of the citizens. In 1874 he was elected to a seat in the City Council for Te Aro Ward, and occupied that position until September, 1878. He was a member of the Chamber of Commerce for many years, and, in 1882, was elected Chairman of that body. In 1888 he attended the Australasian Commercial Conference in Melbourne as delegate of the Wellington Chamber of Commerce, and lately he was elected member of the Harbour Board, as the representative of the Chamber. Possessing considerable business ability, Mr. George was for many years a prominent member of the commercial community of Wellington. For the past seven years he has officiated as managing director of the Wellington Trust and Loan Company. Soon after his arrival, he was appointed Consul for Portugal for Wellington. He was an energetic member of the Masonic fraternity, was one of the founders of the Waterloo Lodge, S.C., and had risen to the dignity of a P.M. of that Lodge. He was also in the Commission of the Peace. Mr. George was a citizen of rare and sterling qualities, possessing a high sense of honour. As a public man he was

universally respected, and as a private citizen he was greatly lamented by a large circle of friends.

Mr. George was elected an Associate Member of the Institution on the 3rd of February, 1880.

WILLIAM JAMES, son of Mr. Edward James, J.P., of Greenbank House, Plymouth, was born on the 15th of November, 1854. He was educated at the private school of Dr. P. Holmes, of Mannamead, in the vicinity. He then served a pupilage of three years from 1872 to Mr. S. W. Jenkin, during which time he was engaged in connection with the parliamentary- and working-plans and sections of several branch lines for the Cornwall Minerals Railway, the Fal Valley Railway, and the Truro and Penzance Railway; then for one year (1875–76), was a student at the School of Practical Engineering at the Crystal Palace under Mr. W. J. Wilson. In 1876 he went to India, but, failing to obtain employment as an engineer, he became a pupil of Mr. H. Whymper, of the Murree Brewery, and was occupied for fifteen months on the water-supply for the Murree Brewery Company in the Punjab. On the conclusion of this work, Mr. James proceeded to Calcutta, where he was at once engaged by Messrs. Mitchell and Co., engineers and contractors, in which firm he, in 1881, became a partner. He was first employed in building bungalows, machine-shops, engine-sheds, &c., for the Northern Bengal State Railway at Saidpore, and afterwards, during the year 1879, was in charge of the construction of 10 miles of the Darjeeling Steam Tramway.

He was also concerned in the making of a road through the Teesta Valley, and on the Bengal Central Railway, the Calcutta drainage works, the Dacca and Mymensing Railway, and the Patna and Bankipore Tramway.

During the last two years of his life he was the resident partner in the firm of Messrs. Walsh, Lovett, Mitchell and Co., contractors for the Tansa water-works, for bringing a large supply of good water to the City of Bombay. During this time he had in the working season from six thousand to ten thousand men under his charge, but the anxiety arising from his responsibilities acting on a frame already much weakened by jungle fever, was too much for him, and he died somewhat suddenly from heat apoplexy at Wasind on the 16th of February, 1889, in his thirty-fifth year.

In his intercourse with his friends, Mr. James had the faculty of

attaching them to him very closely, while by his straightforward and truthful manner he secured not only the esteem but also the affection of those with whom he came frequently in contact.

Mr. James was elected as Associate Member of the Institution on the 7th of March, 1882.

THOMAS SYDNEY POLLARD was born on the 1st of September, 1859. He was educated with a view to following the profession, and on the 1st of January, 1877, was articled to Mr. Sturges Meek, Chief Engineer to the Lancashire and Yorkshire Railway Company. On the completion of a three-years' term he was placed under Mr. William Hunt as Assistant Resident Engineer on the same Company's Shawforth Branch Extension. From December, 1881, to May, 1884, he occupied a similar position on the widening to four lines of rails, of the line between Mirfield and Huddersfield, after which he became Assistant Resident Engineer on the Hindley and Pendleton Branch.

In June, 1889, Mr. Pollard left England to fill a lucrative appointment, in connection with a railway under construction, near Manilla, in the Phillipine Islands. Only a few days after his arrival, and before he had been able to enter upon his duties, he was attacked by cholera, which proved fatal on the 9th of August, 1889.

Mr. Pollard was elected an Associate Member on the 12th of January, 1886.

JAMES RHIND was born at Glasgow on the 31st of May, 1848, and served his apprenticeship as a Mechanical Engineer with Messrs. J. and G. Thomson, engineers and shipbuilders of that city, from 1861 to 1866. He was afterwards employed in the locomotive department of the Caledonian Railway, and at the Lancefield Dock, Glasgow.

In 1873 he went to India, and served on the Holkar State Railway, and afterwards on the Rajputana State Railway in the locomotive department, receiving certificates of good service from his superior officers. He returned to England in April, 1876, and for some time improved his knowledge of locomotive work in the workshops of Messrs. Dubs and Co., Glasgow.

Being repeatedly urged by his friends to do so, he returned to

India, and was employed with Mr. Alexander Izat on the Dhond-Manmád State Railway, and gave such proof of ability and thorough grasp of his work, that in 1880 he was appointed Locomotive Superintendent of the Bhávnagar-Gondal State Railway in Káthiawar. While holding this appointment, with very limited appliances, he built the whole of the workshops, put up the machinery, and fitted up the entire rolling-stock for the line. Mr. Rhind managed the locomotive department on this line, under Mr. W. C. Rennie, and afterwards under the late Mr. Henry Dangerfield, who highly appreciated his abilities and work. In 1883 Mr. Alexander Izat, on taking charge of the construction of the Bengal and North Western Railway, at once applied to Government for and obtained the services of Mr. Rhind as Locomotive Superintendent. Here again the latter did excellent work, and besides equipping the line with rolling-stock, built a number of steamers and flats for the Ganges Ferry, at Digha Ghát, near Bankipore, and also for the crossing of the Gogra River, near Ajoodhia.

In August, 1887, he came home on three months' privilege leave, and seemed to be in perfect health. During this leave he inspected work being done in Glasgow in the preparation of a flotilla to transport loaded wagons across the Ganges between Sonepore and Digha Ghát. These steamers he put together at Sonepore on his return to India, the various parts having been shipped from Glasgow to Calcutta. They have greatly facilitated the goods traffic at this ferry.

In September, 1888, there was an unprecedented fall of rain in the district served by the Uska branch of the Bengal and North Western Railway. Certain protective and irrigation embankments were swept away, the country for miles was submerged and a small bridge on the railway carried away.

In the absence of Mr. Izat, the Agent and Chief Engineer, at a Railway Conference in Simla, Mr. Rhind, accompanied by the traffic superintendent, at once proceeded from Gorakhpur by special train to arrange for repairing the line and carrying on the traffic. After a hard day's work Mr. Rhind was walking back from the breach in the railway to his carriage, when he suddenly dropped down dead. This was on the 11th of September, and the cause of death was heart disease, the existence of which was altogether unknown and unsuspected.

Mr. Rhind was a very hard-working, energetic officer, and showed conspicuous ability in the discharge of his duties as a Locomotive Superintendent. He was eminently trustworthy,

very careful never to promise more than he could perform; accurate in all his estimates and returns, full of resource in the presence of difficulties, and economical in the conduct of his work. He was cautious in forming his opinions, deliberate in judgment, habitually calm in his demeanour, and measured in speech. He ruled his subordinates firmly but very kindly, and by his quiet, unassuming manner endeared himself to all those around him. His loss, both as an officer and friend, was very deeply felt. He was buried at Gorakhpur, a special train being run up the line for the purpose of bringing all those who wished to attend the funeral. One of the leading Indian papers in noticing his sudden and untimely death said:—"In a professional sense, we are told, he was a man whom it will be almost impossible to replace, whilst as an individual he was widely known as he was everywhere respected."

In April, 1886, he was promoted to be Captain in the Volunteer Forces of India, in the Presidency of Bengal, and held that rank until death put an end to a promising and eminently useful career.

Mr. Rhind was elected an Associate Member of the Institution on the 1st of May, 1883.

THOMAS SUMMERS was born at Southampton on the 27th of November, 1855.

At the age of seventeen he entered on his apprenticeship with the firm of Messrs. Day, Summers and Co., Northam Iron Works, Southampton, of which his father was a principal. After serving his time he entered into the service of Messrs. John Elder and Co., Glasgow, and was a draughtsman in their engineering branch, where he earned the confidence of the head of that department. From Glasgow he joined the firm of Messrs. Bertram and Co., engineers, Edinburgh, and occupied a leading position in their drawing office.

In January, 1881, he entered into partnership with his brother William, and they purchased the business of Messrs. William Savory and Son, engineers and millwrights, Gloucester, which has since been carried on under the style of T. and W. Summers, and has gained a reputation for high-class workmanship and careful design. The late Mr. Summers paid special attention to the machinery for manufacturing linoleum, and has invented several improvements in this branch of engineering. He was elected an Associate Member of the Institution on the 31st of May, 1885. He died on the 26th of December, 1889.

ALFRED HOPE WOOD, son of Mr. Daniel Wood, was born at Hastings, on the 29th of March, 1826, and received his education at the school of a Mr. Banks, Bleak House, in that town. In his fourteenth year, he began life as a junior clerk to the late Mr. W. Ginner, then manager of the Hastings Gas Company. From that date up to his retirement in 1887 he was uninterruptedly associated with the Company. When Mr. Wood entered the service of the Gas Corporation the latter's offices were in a small building in a back yard in Winding Street, its insignificance being a strong contrast to the commodious offices now possessed by the Company in Queen's Road. The subject of this notice, began in a humble way, his duties consisting chiefly in having to attend to the books and run to and fro with messages. There were not more than about five men then in the Company's employ, and one gas-holder was sufficient to supply the gas consumed, the customers numbering not more than two or three hundred. Mr. Wood saw the second gas-holder built as well as destroyed, and about the year 1847 or 1848 the third was constructed. The size of the gas-works went on growing year after year, and the number of consumers increased with the rapidly rising population, and with this progress grew Mr. Wood's importance and usefulness. He stuck at his work with a persistence and reliability that characterized the whole of his career, the duties of his working hours being supplemented by the studies and self-education to which he devoted a large amount of attention after business was over. From fourteen years of age till long after he obtained his majority, and at a period, too, when half-holidays and the relaxations from business so common in the present day were few and far between, it was his habit to rise early every morning, winter and summer, and to laboriously study until breakfast-time. In the study of practical chemistry his labours were unremitting, and in later years proved of utility to him in his professional career. Mr. Ginner resigned his position as Manager to the Company, and Mr. Wood was appointed, in January, 1857, Engineer and General Manager. He had made himself competent for this position almost unknown to anyone; he had sufficient foresight to see that the manufacture of gas would in the future assume a more scientific position in the world, and he worked himself up to meet that altered condition of things.

In the early days of his connection with the Gas Company, nobody knew anything about the quality of gas, or the measures that should be taken to test it. Mr. Wood started an analysis of

the gas about the year 1859, previous to which there was no record kept of the quality. In addition to rearranging the works of his own Company, at a cost of £40,000, Mr. Wood erected gas-works at Robertsbridge and Battle. Despite his arduous duties, he found time for other work. For years he was a constant lecturer at the now defunct Mechanics' Institute, the Historical and Philosophical Society, and other Associations in Hastings. Among other scientific subjects on which he lectured were:—"Coal Combustion," "Peculiarities of Combustion," "The Manufacture of Gas," "New Inventions in Gas," "The Science of Light," &c. He also published a few pamphlets, some of which went through several editions, notably his "Guide to Gas-lighting," "Ventilation," and "Coal Storage and Spontaneous Combustion of Coals." He likewise, some years ago, wrote one on the subject of electric light, in which, whilst admitting that there was a future before the more modern mode of illumination, he strongly urged the opinion that there was no need for gas shareholders to tremble as to the result. He was elected an Associate of the Institution on the 5th of December, 1871, and on the division of that class in 1878 was graded Associate Member.

He was a leading member of the British Association of Gas Managers (now the Gas Institute), as well as first President of the Southern Association of Gas Engineers and Managers. He died on the 15th of September, 1889; and the large concourse of mourners at his funeral, in the Hastings Borough Cemetery, testified to the respect in which he was held as a good citizen and an upright man.

EDWARD WALTER NEALOR WOOD was born in London on the 11th of January, 1856; he was the only son of John Turtle Wood, the antiquarian, whose name is best known in connection with the discovery of the Temple of Diana, at Ephesus.

Mr. Wood was educated at Rossall and Finchley, and was articled in 1873 to Mr. William Baker, Engineer-in-Chief of the London and North Western Railway. During his pupilage he acted for a time as assistant to Mr. Louis French, the Resident Engineer on the Newry and Greenore Railway. Subsequently he was entrusted by Mr. Baker with the charge of the boring operations in connection with proposed works for the improvement of the old Holyhead Harbour.

On the expiration of his pupilage, in 1876, Mr. Wood was appointed Assistant Resident Engineer on the Holyhead Harbour

Works, where he remained till 1881, being then transferred in the same capacity to Bangor, on the construction of the Bangor and Bethesda Branch of the London and North Western Railway. In 1882 Mr. Wood resigned this appointment, and for the next couple of years he assisted in the preparation of several schemes for parliamentary deposit, and in other works of a minor description.

In October, 1884, he proceeded to India on a three years' agreement with the Great Indian Peninsula Railway Company, and held during that period the appointment of Resident Engineer at Sholapur, returning to England in February, 1888. In the following December he was appointed Resident Engineer on the Cabezas del Pasto Railway, Huelva, South Spain, which position he held at the time of his death, which occurred on the 30th of August, 1889.

Mr. Wood was elected an Associate Member of the Institution on the 7th of February, 1882. He was previously a Student, and while in that class was awarded, in 1881, a Miller Prize for a Paper on "The Holyhead Harbour Works."

Mr. Wood was of a peculiarly happy, buoyant disposition, ever ready to see the bright side of life, which, combined with a generous kindly nature, and a capacity for unswerving friendship, endeared him to all those with whom he was brought into intimate relations.

SIR JAMES FALSHAW, Bart., J.P., D.L., F.R.S.E., was born in Leeds on the 21st of March, 1810, and passed peacefully away, after a life of hard work, at the ripe age of nearly eighty years, on the 14th of June, 1889.

James Falshaw sprang from an old yeoman family, long settled in the valley of Coverdale, in the North Riding of Yorkshire. His father, William Falshaw, a wool merchant in Leeds, married Hannah Shaw, and by her he had fourteen children, of whom James was the sixth. Young Falshaw received his early instruction under Mr. Jonathan Lockwood, a local celebrity in his day, in whose establishment in Brunswick Terrace, Leeds, he was a fellow pupil of Sir John Hawkshaw, Past President Inst. C.E. In the year 1824, at the age of fourteen, he was articled for a term of seven years to Mr. Joseph Cusworth, architect and surveyor, Leeds. This gentleman appears to have been a hard master, as his pupil was wont to relate how he worked from nine o'clock in the morning until nine o'clock at night—Saturdays included—all the year round. During his apprenticeship Falshaw gave special attention to the

theory and construction of skew arches, and overcame for himself the difficulties, at a time when such work was new and not generally understood. In after life he attributed his first important advancement to his successful mastery of this subject. When his long seven years expired in 1831, the great tide of railway construction had just began to flow, and Mr. Falshaw seems to have been caught by it immediately upon gaining his freedom. Messrs. Hamar and Pratt, contractors for the Leeds and Selby Railway, recognizing the ability and determined character of the young man, engaged him as agent in charge of a section of that line, in which capacity he served them for three years, evidently to their satisfaction, for, on the completion of the work, he was appointed to take charge for them of the construction of the Whitby and Pickering Railway, a line remarkable alike for steep gradients and for the sinuosity of its course. In this contract he acted in the multiple capacity of agent, engineer, book-keeper, and cashier, and had full charge of the works, with the assistance only of two travelling gangers. The contractors left him in entire command, and seldom visited the works, which he brought to a successful completion in the spring of 1836.

During these five years Mr. Falshaw, with his untiring energy and zeal, gained, as may be readily imagined, a thorough knowledge of railway work, and he revealed, in the responsible positions which he held, a character of sterling worth and integrity, which by no act of his in after life did he ever forfeit.

In the year 1836, at the age of twenty-six, he became principal assistant to Mr. George Leather, of Leeds, Engineer of the Aire and Calder Navigation, Goole Docks, &c. He remained with that gentleman for seven years, during which period he was engaged in preparing parliamentary- and working-plans and surveys for various schemes, many of which were successfully carried through Parliament and executed. Amongst these may be mentioned the Leeds Water-Works, for which an Act was obtained in 1837. This work consisted of a storage-reservoir 50 acres in extent at Eccup, 7 miles from Leeds; a second storage-reservoir at Weetwood; a service reservoir at Woodhouse Moor; and a tunnel, 1¼ mile long between Eccup and Weetwood. Plans of the Stockton and Hartlepool Railway were prepared in 1837, the works commenced in the following year, and completed in the spring of 1841, Mr. (now Sir John) Fowler, Past President Inst. C.E., being Resident Engineer. The chief work on this line was the construction across Greatham Marsh of a brick viaduct of ninety-two arches, the foundations of which were so bad that piles had to be driven from 30 to 60 feet

in depth. The railway works were successfully and rapidly completed, and were highly eulogized in the newspapers of the time.

The Bradford Water-Works scheme was reported on in 1838, plans prepared in 1840, the Act obtained in the following year, and the work executed in 1842 and 1844. The experience gained on these and other works stood Mr. Falshaw in good stead in after life.

In the spring of 1843 Mr. Falshaw commenced business at Leeds on his own account; but he did not, it appears, entirely sever his connection with Messrs. Leather, for a year later he was engaged with Mr. J. W. Leather and Mr. R. O. Hodgson in the opposition to the proposed valley line of the Leeds and Bradford Railway, taking levels, plotting sections, making estimates, and giving evidence before Committees of the House of Lords.

It was at this time that a turning point in his career took place. Mr. John Stephenson, of the firm of Messrs. John Stephenson and Co. (with whom were associated Mr. William Mackenzie and Mr. Thomas Brassey), offered him the charge of the construction of the Lancaster and Carlisle Railway, the contract for which, as a single line, had been taken by the firm. After due consideration, Mr. Falshaw decided to accept this offer, and the month of June, 1844, found him installed at Kendal, vigorously discharging his new duties, purchasing sleepers, inspecting quarries, and arranging terms with landowners. In the following month he was first introduced to Mr. Brassey at Carlisle, at a conference between the engineers, Messrs. Locke and Errington, and the contractors. It is worth recording that at this meeting Mr. Locke decided that "as many stone blocks were to be used as possible," which order was, curiously enough, qualified six months later by Mr. Errington. In conversation with Mr. Falshaw, Mr. Errington said, "I have no objection to sleepers being used in the district between Shap and Kendal; although Mr. Locke has an objection to them, I have not, and you may use them." Great difficulties and delays were encountered in gaining possession of the land, and these sorely tried Mr. Falshaw's patience, for he had agreed with Mr. Brassey, at a meeting of the directors in August, to finish the line in two years' time. In November, however, the Board decided to double the line, at an extra cost of £80,000. Mr. Falshaw was not destined to carry this work to completion, for in the early part of the following year, 1845, he was very busily engaged in London, with Mr. Brassey and Mr. Stephenson, making estimates for the Scottish Central, the Scottish Midland, the

Caledonian, and other important railways, and in attending Committees of the House of Commons. On one of these occasions he heard Mr. Brunel, in giving evidence in favour of the Hawick Railway, say that he "saw no difficulty in locomotives ascending gradients of 1 in 70, with $\frac{1}{4}$ mile curves at a speed of 20 or 30 miles an hour," the boldness of which statement created a profound impression upon those present.

The tender of Messrs. Stephenson, Brassey and Mackenzie for the Scottish Central and Scottish Midland Railways and the Castlecary branch of the Caledonian Railway having been accepted, it was arranged that Mr. Falshaw should conduct the operations on terms very favourable to himself. In July, 1845, he therefore removed to Stirling. The line commenced at Greenhill, where it joined the Edinburgh and Glasgow Railway, and extended to Forfar, *viâ* Larbert, Stirling, Dunblane, Crieff, Perth, and Cupar Angus, a total length, including branches, of over 100 miles, 70 of which were double line. The heaviest portion of the work was the Moncrieff Tunnel, 1,200 yards in length. In carrying out this important undertaking, Mr. Falshaw developed great administrative ability. He had at his command a force of eight thousand men, and the works were accordingly prosecuted with great vigour. Mr. (now Sir Charles) Hartley joined his staff in the autumn of 1845, and was placed in charge of the Dunblane district. On the 1st of March, 1848, after an inspection by Captain Wynne, the section of the Scottish Central Railway between Greenhill Junction and Stirling was publicly opened for traffic, and the remainder of the line to Perth on the 22nd of May following. Two months later the Scottish Midland Railway, from Perth to Forfar, was also opened for traffic. The entire work having been thus completed in three years, the contractors were rewarded with a substantial bonus.

On the 5th of January, 1849, a public dinner was given in Mr. Falshaw's honour at Stirling. Immediately upon the opening of the Scottish Central and Scottish Midland Railways, the directors of both companies resolved to let to Mr. Falshaw the contract for the upholding of their whole undertaking for a term of seven years. He accordingly entered upon this work on the 1st of January, 1849, and the contract terminated satisfactorily in due course in 1855. During this period he also executed many additional works in connection with these railways.

In 1851 his connection with the firm of Messrs. John Stephenson and Co. ceased. Mr. Stephenson had died in 1848, but Mr. Falshaw never lost touch with Mr. Brassey, who frequently consulted him and requested his assistance. A sincere friendship was

maintained between the two until Mr. Brassey's death in 1870. In October, 1853, they met at Shrewsbury, and agreed, upon terms of equal responsibility and profit, to take the contract for the construction of the Inverness and Nairn Railway, Mr. Falshaw having the entire management. He accordingly, in the following year, sold his house at Perth and settled at Nairn. The line to Nairn was opened on the 5th of November, 1855, and soon afterwards the directors agreed with Messrs. Brassey and Falshaw for its extension to Elgin, a total distance from Inverness of 37 miles. This work, which was conducted under considerable difficulties, arising from the rugged character of the country and the liability of the mountain streams suddenly to become raging torrents, was successfully completed in the spring of 1858. A few months afterwards, the line from Aberdeen was carried forward to Elgin, and the Highlands of Scotland were connected by rail for the first time with the southern portion of the kingdom.

Mr. Falshaw thoroughly enjoyed his four years' residence in the ancient town of Nairn, and his presence there appears to have been much appreciated by the inhabitants, who gave a public dinner to him in the spring of 1856, the Provost presiding. On the 4th of November in the same year, he was elected a member of the Town Council, and only three days afterwards he was unanimously elected Senior Bailie of the royal burgh. His work in the North being completed, he quitted Nairn on the 31st of August, 1858, to take up his residence in Edinburgh, bidding an affecting farewell to the friends who came in crowds to the station to take leave of him. In Edinburgh, to which beautiful city he had ever since his first visit to Scotland been greatly attached, he hoped to spend the remainder of his life in comparative ease and retirement, but his character, his capacity for work, and his great business ability were too well known to allow of his leading a quiet life. Before leaving Nairn, he had entered into contracts for the construction of the Denny branch of the Scottish Central Railway, and for the Port Patrick, Stranraer, and Glenluce Railway. These were completed in due course in the years 1859–60.

On his return to Edinburgh in January, 1861, after a tour in the United States and in Canada, he was elected without opposition to represent St. Luke's ward in the City Council, and three years afterwards, he was elected a magistrate of the city. In October 1861, he was invited to, and accepted, a seat on the board of directors of the Scottish Central Railway.

In 1862 he entered into partnership with Messrs. Morkill and Prodham, two of his former assistants, in a contract for

the construction of the Berwickshire Railway, each taking an equal share in the risk and profit of the undertaking. In 1864 he again associated himself with Messrs. Morkill and Prodham in a contract for the construction of the Blaydon and Conside branch of the North Eastern Railway in the county of Durham. The completion of this work in December, 1867, closed his career as a railway contractor.

About this time, he became a director of the Inverness and Aberdeen Junction Railway, now merged into the Highland Railway Company, and also of the Cambrian Railway Company. He was also for many years a director of the Central Bank of Scotland, which, in 1868, was amalgamated with the Bank of Scotland. This arrangement was effected at a meeting which the directors of the two companies held at Mr. Falshaw's house in Edinburgh.

In the spring of 1867, he made a prolonged tour in Italy in company with a friend, and in August of the same year, at the invitation of the Lord Provost, he accompanied the Commissioners of Northern Lights, in their steam yacht "Pharos," in one of their pleasant trips to the remote points at the extreme North and West of Scotland, visiting amongst other interesting places the lonely Island of Foula, the female section of which primitive community fled at the approach of the strangers. He was fortunate in being one of the recipients of an invitation from the Khedive of Egypt, to representatives of this country, to be present at the grand ceremonial of the inauguration of the Suez Canal in the year 1869, by the Empress Eugenie of France.

In November 1872, after an absence from the Council of five years, he was again invited to enter municipal life, and was elected by a large majority to represent St. George's Ward. In March 1874, Lord Provost Cowan retired from office, in consequence of having been elected Member of Parliament for the city, and Mr. Falshaw was unanimously chosen to fill his place *ad interim*. At the November election in the same year he was reinstalled, with acclamation, by the assembled Council in the office of Chief Magistrate of the city for the usual term of three years. It is a notable fact that he is, so far, the only Englishman who has ever occupied that position. During his tenure, Lord Provost Falshaw devoted his mind to the interests of the city, and he heartily and freely gave the benefit of his ripe experience, technical knowledge and great energy, to the advancement of the numerous important measures then engaging attention. It is chiefly to him that many of the features which add to the adornment of the city,

and not a few of the comforts of the community, owe their existence. Prominent amongst the many schemes with which he was specially identified are, the Edinburgh Water-Works, Moorfoot scheme; the acquisition of the Arboretum; the widening of Princes Street, by the annexation of a portion of the gardens, thus making it probably the finest street in Europe; the roofing of the Waverley Market, which had the double effect of enhancing the efficiency of the market and blotting out an eyesore; the widening of the North Bridge, and the opening to the public of the West Princes Street Gardens, formerly private property. All these reforms and improvements he saw carried out, and they are undoubtedly of the greatest advantage to the city. His high professional skill was of the utmost service in carrying out the Moorfoot water scheme. "His bearing in the council-chamber was notable in that he pierced to the heart of a subject, made no long-winded speeches, but pronounced a dogmatic but wise opinion in a few forcible words." Accustomed himself to deeds, not words, he was impatient of unnecessary talking on the part of others; it is no wonder, then, that the business at the council meetings during his tenure of office was transacted in about half the usual time. His action in urging forward and helping to carry out the Scottish National Memorial to the Prince Consort is specially memorable, and it was universally admitted that he got no more than his reward in the baronetcy which the Queen conferred upon him. This event took place on the 17th of August, 1876, when Her Majesty visited Edinburgh.

At the close of his municipal career, which terminated with his Lord Provostship in November 1877, Sir James was publicly presented with a valuable testimonial, consisting of a life-sized portrait of himself, subscribed for by his fellow-citizens as a mark of their esteem and appreciation of his services, and at the same time, Lady Falshaw was presented with a diamond bracelet and ring. Prior to his death, Sir James presented the portrait to the Council, and it now hangs in the Council-chamber.

In February 1875, when he was busily engaged with city affairs, Sir James received and accepted an invitation to a seat on the Board of Directors of the North British Railway Company. At that time the building of the unfortunate Tay Bridge, designed by Sir Thomas Bouch, was already in progress, and Sir James took in this work, as in everything with which he was connected, a conscientious interest. The terrible accident which befel the structure, in December 1879, was a great shock to him; but it is interesting to note that the directors, who were hurriedly assembled

to consider the matter only two days after the occurrence, boldly resolved before they parted to rebuild the bridge.

A new Bill was obtained in the spring of 1881, and a contract was made in October of the same year with Mr. William Arrol, to carry out a new design, prepared by Messrs. Barlow and Son, for the sum of £615,000. The new bridge, which carries a double line, was most successfully finished and opened in May 1887.

In March 1881, Sir James was elected Deputy-Chairman of the North British Railway Company, and in August of the same year, he became Chairman of the Forth Bridge Company, provisionally formed to carry out the design of Messrs. Fowler and Baker. When the board of this important company was finally formed in July 1882, it was composed, besides the North British representatives, of the Chairmen of the three great English railways, viz., the Great Northern, the Midland and the North Eastern, who had joined in the promotion of this gigantic undertaking, and at the first meeting, Sir James was re-elected Chairman of the Company. He saw the Bill successfully carried through Parliament, the work fairly launched in progress and almost completed. The contract was let to Messrs. Tancred, Arrol and Co., in November 1882 for the sum of £1,600,000. Sir James took an absorbing interest in this great work from the time of its inception until his death.

In the month of August 1882, on the decease of Mr. John Stirling, the Chairman of the North British Railway, Sir James was unanimously elected to fill his place, and he continued to preside over the affairs of the company until January 1887, when, owing to advancing age, he felt the need of repose. He accordingly retired in favour of the Marquis of Tweeddale. The directors, however, were desirous of retaining his services, and the Deputy-Chairman, Mr. Beaumont, resigned in order that Sir James might take his place. In connection with the North British Company, Sir James was also on the Boards of the City of Glasgow Union Railway, the Edinburgh Suburban Railway, the Bo'ness Harbour Commission, the Burntisland Dock Commission, and numerous committees. He was also for some years Convener of the Works Committee of the Edinburgh and District Water Trust, Chairman of the Works Committee of the Leith Dock Commission, a Curator of Edinburgh University, and a Governor of the Royal Infirmary. In the year 1880, he filled the important public office of Master of the Merchant Company, a body of great wealth and influence in Edinburgh, which controls extensive estates and several of the famous educational hospitals of the Scottish capital. Sir James was also on the Boards of various manufacturing, shipping and

insurance companies. In fact, positions of trust and honour fell to him as the natural result of ability and integrity; but for the last year or two of his life, he was unable to take an active part in his affairs, as his health and strength were failing. The *Glasgow Herald* of the 15th of June, 1889, says:—

"Sir James was quite noted in Edinburgh as a Chairman of meetings. Naturally a man of few words, when anything had to be done, his speeches were marked with a directness and brevity seldom to be met with. He was opposed to needless speech-making on the part of others, and always endeavoured to bring matters to a point as speedily as possible. Though this aspect of his character made him appear rather 'short' and 'gruff,' it was only a sign of the sterling purposeful mind. In private he showed his genial kindly disposition, while his work remains to testify, not only to his business capacity, but to his love of his fellow-men."

The *Scotsman* of the same date, says:—

"He was a man of indomitable energy and firm purpose. Outwardly of a brusque demeanour, and inwardly possessed of a swift mental way of arriving at the heart of things, he was impatient of public palaver, and his laconic methods of conducting council and railway meetings occasionally staggered the advocates of liberty of speech. The white rose of his crest was a fitting symbol of a life of sterling integrity, and his motto '*In officio impavidus*,' a very pithy way of expressing his conduct in public life."

Sir James Falshaw was elected an Associate of the Institution on the 23rd of May, 1854.

JAMES GRIERSON was born at Edinburgh on the 10th of October, 1827. His father, who was early engaged on engineering and building operations, subsequently removed to Birkenhead, as a member of the engineering staff of the Chester and Birkenhead Railway. At this place young Grierson finished his schooling, and in 1843 he entered the office of Messrs. Dickson and Yarrow, the Chief Engineers of the line, upon the construction of which his father was employed. His career here was nearly nipped in the bud, for after a short time he was, apparently without rhyme or reason, sent home. His father, greatly distressed, wrote to Mr. Dickson, inquiring if the dismissal were due to "any dishonesty or untruthfulness." The reply was to the effect that it was "neither for dishonesty nor for untruthfulness, but for sheer wilful waste." It eventually turned out that young Grierson had taken a whole clean sheet of paper whereon to write the name of a caller.

He was reinstated, but the incident was a lesson in economy which he never forgot.

About this time he narrowly escaped a fatal accident. A locomotive being at rest over an engine-pit, he and another boy got into the pit "to examine the works," when the driver not knowing they were there, discharged the steam, which so scalded Mr. Grierson's companion that it ultimately caused his death.

On the completion and opening of the Birkenhead Railway, towards the end of 1847, Grierson went into the Traffic Department, and afterwards into the Accountant's Office, when he availed himself of the opportunity thus afforded of making himself thoroughly master of the administrative details of the several departments. The determination to make his way upward was even then alive within him; but it was accompanied with the resolve that he should do so by honest work, waiting for his reward when its worth should make itself fully recognised. In all he did he was never superficial. Whatever he had to do he did thoroughly—leaving no loose ends or imperfect conclusions, and guided always by an intelligent interest, which sought for a principle in everything, and looked ahead for further developments, where existing arrangements were imperfect.

He read every scrap of literature bearing upon railways which he could lay his hands upon, and even procured files of the *Times* in order to wade through its articles and notices upon railway enterprise.

He was only twenty-three when he was placed in a position of great responsibility. The Shrewsbury and Birmingham, and Shrewsbury and Chester Railways had both been opened for traffic, and the respective Boards of Directors soon became impressed by the difficulties inseparable from diverse and distinct management. They therefore determined to work their two lines as one, by means of a "Joint Through Traffic Committee." The then two leading Directors, Mr. Robert Roy, for the Shrewsbury and Chester, and Mr. George Knox, for the Shrewsbury and Birmingham, offered the appointment of secretary and manager to this Joint Committee to Mr. Grierson, of whose fine abilities they had been satisfied by close observation during preceding years. They had no cause to regret their selection, for young though he was, he very soon proved himself equal to his position, and rendered the two companies zealous and very valuable assistance, not only in increasing the traffic, but also in the struggle which soon afterwards took place between the London and North Western and Great Western Railway Companies, for the possession of these railways, and also

of the Chester and Birkenhead line. At this time Mr. Grierson greatly advanced his influence by gaining the confidence of his directors, and the estimation and good will of the traders. As his directors were strongly in favour of the Great Western alliance, considering it the best policy for the success of their railways, Mr. Grierson put his heart and soul into the parliamentary struggles, which ended in making them part of the Great Western system, and worked most earnestly for their amalgamation until it was accomplished. Even at this early period of his career, he gave more than promise of the reputation which he subsequently acquired as a witness before parliamentary committees.

At the time when this amalgamation was sanctioned the financial circumstances of the Great Western Company were not good, neither was its immediate prospects very bright. Mr. Grierson's name was a stranger to the proprietors, and had not yet become familiar to the outside railway world. Probably, therefore, with a view to giving confidence to the shareholders, the directors, instead of giving him the position he had so well earned, determined to appoint, first, Captain Codrington, and afterwards Mr. W. L. Newcombe, men of established reputation in the railway world, to look after their interests in their new territory, assigning to Mr. Grierson a subordinate place under them. At this he, no doubt, felt sore for the time. It was a check, the first and last to his honourable ambition, and he could not but be sensible of some disappointment that it should have been thought necessary, after his strenuous and successful exertions in effecting an alliance, the fruits of which no one was better fitted than himself to develop. The decision was the more painful, as the entire confidence shown him by his former directors justified the expectation that this task would be placed in his hands. At first he was almost disposed to regard his appointment to a subordinate position as a "vote of want of confidence." But although the acceptance of another appointment, as general manager to one of the leading railways, was pressed upon him, with nearly ten times the salary he was then receiving, he was not slow in deciding to refuse it. In this resolution he was strengthened by the advice of a friend older than himself, and he determined to "bide his time," continuing his position with, and loyalty to, those railways which had given him his first start in life, and being also satisfied that in time he could show that he was not unworthy of the entire confidence of his new masters. It is, however, scarcely necessary to say, that both Captain Codrington and Mr. Newcombe, as was to be expected from their well-known kindly and gentlemanlike feeling, studiously

endeavoured to make Mr. Grierson's position with them as agreeable as possible, and a lasting friendship and regard for each other was the result.

On Mr. Newcombe's appointment as General Goods Manager in 1856 over the whole of the Great Western system, and consequent removal to Paddington, Mr. Grierson was again put in charge of his old district, extended to Birmingham, with South Staffordshire added, and with offices at Wolverhampton. In the following year Mr. Newcombe returned to the Midland Railway, and Mr. Grierson succeeded him as the Great Western General Goods Manager, and went to Paddington, where he soon became a potential instrument in developing the resources of the vast district under his superintendence. Mr. Grierson was then only twenty-nine years old, but he had by this time made himself so thoroughly master of the company's business, that his claim to the appointment did not admit of question. His value was so thoroughly appreciated that, on the retirement in 1863 of Mr. Charles A. Saunders from the office of secretary and general superintendent, Mr. Grierson was appointed to succeed him with the title of General Manager.

And here, perhaps, a circumstance may be mentioned as illustrating the perfect unselfishness of his disposition. The late well-known Mr. A. C. Sheriff had been General Manager of the West Midland Railways for many years, and up to their becoming part of the Great Western system, and from his age and longer experience he might have been considered to be the best entitled to the position created on Mr. Saunders's retirement. Before seeking it for himself, Mr. Grierson took care to ascertain from Mr. Sheriff what his wishes were in the matter, telling him at the same time that, if he were a candidate, he should at once decline the appointment, if it were offered to him; but would be very greatly pleased to work under Mr. Sheriff as second in command. It was not until Mr. Sheriff assured him he did not wish the appointment, that he considered Mr. Grierson to be the proper man for it, and that he should have his active support if required, that he accepted the promotion.

That Mr. Sheriff judged rightly, no one could doubt who had watched the career of Mr. Grierson from the time of his appointment as General Goods Manager. Apart from his masterly powers of organization and administration, he had during these years, when the Great Western Company was engaged in important parliamentary conflicts for the protection and development of its system, rendered invaluable service to the company as a witness by his wide and accurate knowledge of details, by the soundness of

his views on the general policy of the company as affecting both the public and itself, and by the clearness and force with which these views were expressed.

During this period also, the protracted negotiations with the West Midland and South Wales Railway Companies, which ended in their absorption into the Great Western system, were entirely conducted by him, with the cordial concurrence of Mr. Saunders and the sanction of the board. Again, the agreements with the London and North Western and the Midland Railway Companies, in consideration of which these companies withdrew their opposition to the amalgamation of the Great Western company with the South Wales railway companies, and which has ever since guided and controlled the relations between those companies and the Great Western, were not only negotiated by Mr. Grierson, but to a great extent reduced by his own hand to the form in which they now stand. The value of these agreements to all the three companies can scarcely be overstated, if only for the reason that they defined the conditions on which competition between them was to be carried on, and put an end to the ruinous cutting down of rates, by means of which railway companies used in those days to abstract traffic from each other. These agreements set the example of the establishment of joint committees of the companies, by which all questions, in which the Great Western and the North Western in the one case, and the Great Western and the Midland in the other, have a joint interest, are discussed and determined, and differences adjusted.

From the hour of his appointment as General Manager, the whole of Mr. Grierson's energies were directed to removing existing impediments to the prosperity of the Great Western system, and to the steady development of its resources. Numerous improvements were from time to time introduced in the working of the line, which eventually told by raising the company from financial embarrassment to its present commanding position. Perhaps the greatest of these improvements was the conversion from the broad- to the narrow-gauge, except from Paddington to Bristol and the south-west of England, where the broad-gauge still continues, but with the narrow-gauge also. In this way the isolation of the Great Western, which had materially retarded its progress, was remedied, and it was brought into communication with all the narrow-gauge railways of the kingdom. The rolling-stock, both of engines, carriages, and wagons, was greatly improved and largely increased, and for comfort and appearance will now compare creditably with that of any other railway in the kingdom. Marked improvements were made in all the stations, most of them having

been entirely rebuilt; sidings at the goods stations, for the better accommodation of the goods traffic, and along the line were largely extended and remodelled, so as to prevent passenger and fast goods trains from being blocked by slower trains, thus ensuring more punctuality, and therefore greater safety, to the travelling public. Under his guidance the line became better equipped for the comfort and convenience of passengers, and was noted for the courtesy and attention of its servants, from guards and station-masters down to porters. Not less important were the judicious amalgamations with existing lines promoted under his advice, notably the Bristol and Exeter in 1876, and shortly afterwards the South Devon and Cornwall Railways; and the construction from time to time of new lines as the emergencies of trade and manufacture demanded. To his far-seeing counsel also is in a great measure due the construction of the Severn Tunnel—nearly 8,000 yards in length, with long and difficult approaches to it. The effect of this measure, in greatly reducing the distance from London and Bristol into South Wales, and from Liverpool and Manchester to Bristol over any existing route, has surpassed even Mr. Grierson's anticipation. It has become a source of great revenue to the company, without diminishing dividends, although a work of gigantic cost. When Mr. Grierson became General Manager, the Great Western system was 1,056 miles only. At his death, it was 2,455 miles. When he entered on that office, its ordinary stock stood in the market at 66. At the time of his death it was 135. What more convincing proof can be desired of the abilities and energy of the man, on whose shoulders the administration of the business arrangements of this vast undertaking practically rested?

In the power of organization, in which not a few of his brother general managers excel, Mr. Grierson was a master. His eye was upon every part of the system for which he was responsible, and he made it his duty to know that all the details of the great machine were carried out in accordance with his general plan. This habit he carried perhaps to a fault—not in so far as the efficient working of the machine was concerned, but in taxing his vital energies so severely, that he inevitably accelerated the day when it could no longer be guided by his powerful hand. It has been truly said of him, that "he possessed and always retained the most absolute mastery of the details of all the departments into which the working of a line of railway is necessarily divided. He was as familiar with the traffic on the smallest branch as with the prospects of some great scheme of extension; and he

knew how many days a sick porter had been off duty. No departmental manager could instruct him, no subordinate could impose upon him." "The one fault for which 'those who worked under him' blamed him, was the carelessness of his own health, which was by his devotion to duty a carelessness to which, there is too much reason to fear, his life was sacrificed. His holidays were few, and of brief duration; and he was far from well when he left England, in the autumn of 1887, to take part in a congress of railway officers, which was held at Milan." Tempted by his proximity to the City of the Doges, he extended his journey as far as Venice. The time was ill-chosen for a visit to Venice, even by a man in vigorous health; but to one in a state of exhaustion from excess of work the malaria of its canals in the hot season was fraught with danger. Hurrying back to England, he arrived in London early on the 30th of September, and spent the remainder of the day in disposing of questions which had arisen in his absence. He was no sooner at home than he developed an illness, the symptoms of which pointed to his blood having become affected with poisonous germs. Still he gave his thoughts to the work of his office, struggling on hopefully to the last. But on the 7th of October he succumbed, to the grief of the numberless friends who loved him as few friends are loved, and to the all but irreparable loss of the great undertaking to which his life had been devoted.

How deeply that loss was felt by the Directors, who for years had reason to know how much the smooth working and the prosperity of the Great Western system was due to their General Manager, was well expressed in their next half-yearly report (January, 1888) to their shareholders.

"By the lamented death of Mr. Grierson, the late General Manager, which occurred in October last, the Company has sustained a most serious loss.

"Closely identified with Great Western interests at an earlier date, Mr. Grierson entered the service of the Company in 1854, and was appointed General Manager, on the absorption of the West Midland lines, in October, 1863.

"Possessed of much force of character, combined with sound judgment and untiring energy, Mr. Grierson was specially qualified to cope with the difficulties consequent upon the large extensions of the Company's system, which were made during his tenure of office; and the Directors cannot express too strongly their sense of his constant devotion to the service, of the ability with which his multifarious duties were discharged, and of the aid which he rendered to them at all times in the organisation and management of the line, contributing in no small degree to the placing of the Company in its present satisfactory position.

"His assistance and counsel were of no less value in the deliberations with other Companies upon matters of common interest to railway proprietors, and the spontaneous and general expression of regret and sympathy which followed his death, testified not only to the appreciation of Mr. Grierson's personal worth,

but also to the high regard in which he was held alike by the railway world and by the various public Departments with whom his position brought him in contact."

Mr. Grierson was buried on the 12th of October, 1887, in Barnes Cemetery, a spot he had almost selected for himself because of the great retirement of its position. The great throng of mourners that assembled on the occasion amply testified how wide was the recognition of his worth in all the relations of life. He died much beloved, and without an enemy, a proof that the saying is unsound, which affirms, that a man who makes no enemies is not a man to inspire respect or love.

Mr. Grierson was elected an Associate of the Institution on the 5th of December, 1855.

JOSEPH HANCOX was born at Tipton, Staffordshire, on the 25th of March, 1827. After a local education, he studied surveying with his brother, John Hancox, engineer of the Birmingham Canal Company, and passed a short time at the Horseley Iron works. Thence, in 1845, he went to the Trent Valley Railway as assistant to Mr. John Jones, agent for the contractors, Messrs. Brassey, Mackenzie and Stephenson. He was employed in similar positions in 1847 on the works of the North Staffordshire Railway, also under Mr. Jones, the agent for Mr. Brassey, and, in 1850, on the Birkenhead, Lancashire and Cheshire Junction Railway under Mr. George Goodfellow, agent for Mr. Brassey. From thence in 1853 he went to Piedmont, where he, in conjunction with the late Mr. Thomas Woodhouse, carried out the contract taken by Mr. Brassey for the construction of the Turin and Novara Railway, and in 1856 he took charge of the works of the Netherton Tunnel, under the late Mr. George Meakin, contractor. Mr. Hancox was then engaged for a considerable period in going over and estimating for Mr. Brassey several lines of railway, notably the Lukmanier, crossing the Alps, the Moldavian Railway, and the Colombo and Kandy, Ceylon; also the Swansea Docks, Spithead Forts, Portsmouth Harbour defences and other works. In 1859 he went to Rio de Janeiro to carry out the contract made by the Rio de Janiero City Improvements Company with Messrs. Brassey and Ogilvie for the drainage of that city, which contract was completed.

At the expiration of that time, he was engaged estimating various works, amongst others the Berlin and Stralsund Railway.

Subsequently he went over the projected works for the Naples water-supply for Messrs. John Aird and Sons, also lines of railway in Poland and Saxony.

In 1877 he returned to Rio de Janiero, and, in association with the late Mr. Alexander Ogilvie, entered into a contract with the Brazilian Government for the rain-water drainage of the city, carried out partially to a successful issue, but never completed, in consequence of financial difficulties on the part of the Brazilian Government, which prevented the completion of a work that would doubtless have tended greatly to diminish the bug-bear of foreigners in that city in the shape of yellow fever. During this time, he executed the works for the water-supply of Santos, in the Province of São Paulo, Brazil.

He was a man of considerable experience, indefatigable, pains-taking, clear-headed, with great patience and good temper under provocation; a most genial manner, and his kindly, simple and unaffected ways attracted and endeared him to all to whom he was personally known, while his unselfish goodness gained him friends and won respect and friendship from those who came under his influence. He died after a short illness at Tunbridge Wells, on the 24th of May, 1889.

Mr. Hancox was elected an Associate of the Institution on the 8th of January, 1861.

SIR HENRY ARTHUR HUNT,[1] C.B., was born at Westminster, in September 1810. He was educated for a surveyor, serving his articles with Messrs. Thurston and Sons, a firm of some note. He subsequently entered the office of Mr. Wallen, who took him into partnership when under eighteen years of age. This partnership lasted only a few months. In 1828, Mr. Hunt commenced business on his own account, taking the late Mr. Charles Stephenson into partnership in 1844, and the late Mr. Harry Jones some twenty years later.

Mr. Hunt in his early life made, single-handed, for Sir Charles Barry, the detailed estimate for the Houses of Parliament. When the great railway companies were constructing their lines, he was largely employed by the North Staffordshire, the London, Brighton and South Coast, the Eastern Counties (now Great Eastern), the

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[1] This memoir has been reproduced, with a few verbal alterations, from the Transactions of the Surveyors' Institution, vol. xxi. p. 487.

District, and the Metropolitan Railways. Most of the railway shops at Stratford were built under his supervision. He also constructed the gigantic brewery of Messrs. Allsopp at Burton-on-Trent.

Among the many building estates which he managed may be mentioned those of the Commissioners of the Exhibition of 1851, at South Kensington; those of the Corporation of the Sons of the Clergy; and the London property belonging to the Dean and Chapter of Westminster, the Dean and Chapter of St. Paul's, the Dean and Chapter of Canterbury, and the Archbishop of Canterbury, till transferred to the Ecclesiastical Commissioners. He also held the important post of consulting surveyor to Her Majesty's Office of Works from 1856 to 1886, and in this capacity was largely concerned in the selection of a site for, and the erection of, the Royal Courts of Justice. In 1871, he was made a C.B. under Mr. Gladstone's administration, and was knighted in 1876 by the Conservative Government then in office.

Throughout the country he was constantly employed as an arbitrator in connection with compensation claims, and, during the latter years of his life, in adjudicating on claims under the special provisions of the Artizans' and Labourers' Dwellings Acts.

Sir Henry was elected an Associate of the Institution on the 4th of March, 1851. He was also a Fellow and a Founder Member of the Surveyors' Institution, and was one of its Vice Presidents for the two years 1868–70.

The last arbitration case in which he was engaged was in connection with the celebrated Thirlmere scheme.

Few men owe their success in life less to chance than did the subject of this memoir. He was naturally gifted with a capacity for hard work, and was indefatigable in the pursuit of any object upon which he had set his mind. He was an early riser throughout his life, being seldom in bed after six o'clock in the morning. Most of his personal characteristics will be fresh in the memory of all. Perhaps the most noticeable of these was the extreme brevity and dryness of speech in connection with matters of business, though it is said he was an excellent and entertaining talker in private and in congenial company.

He was particularly exact in all that he did, bestowing upon it a continuous and concentrated attention of which few men are capable. It was this quality, joined with a wide range of practical knowledge, which made him so acceptable as an arbitrator. He would listen with admirable gravity and patience to the most illogical arguments and the most contradictory statements, without

betraying his opinion of them either by look or gesture. Never was manner more inscrutable. He took very brief notes, being gifted with a most retentive memory, and almost invariably making his awards while the matter and evidence were fresh in his mind.

During the last three or four years of his life, his health, which had previously been uniformly good, became visibly impaired, though he remained in perfect possession of his faculties to the end. His death took place at Folkestone, on the 13th of January, 1889, in the seventy-eighth year of his age.

Sir SAMUEL MORTON PETO, Bart., was born on the 4th of August, 1809, at Whitmoor House, Sutton, in the parish of Woking. At school he early showed a talent for drawing, and while apprenticed to his uncle, Mr. Henry Peto, the builder, at the conclusion of his day's work in the joiner's shop, he attended a technical school, and later received lessons from a clever draughtsman, Mr. Maddox, at Furnival's Inn, and from another architect, Mr. Beazley, when he became acquainted with the late Charles Mathews, the actor, who was articled there. Mathews' heart was by no means in this profession, and Sir Morton earned his gratitude by taking home his drawings and finishing them for him, thus early showing the kindly thoughtfulness for others, a leading feature in his character. After three years in the carpenter's shop, Sir Morton went through the routine of bricklayers' work, and prided himself on being a first-rate performer, and able to lay his eight hundred bricks per diem. He was later entrusted with the supervision of buildings undertaken by Mr. Peto, among others a house for Horace Twiss, in Carlton Gardens, and Raymond's Buildings, in Gray's Inn. His articles expired in 1830, and in that year Mr. Peto died, and left the business to his two nephews, Mr. Thomas Grissell (afterwards of Norbury Park), and Sir Morton Peto. The firm of Grissell and Peto, during their partnership, executed many buildings of importance. The first was the Hungerford Market, obtained in public competition; afterwards they built the Reform, Conservative, and Oxford and Cambridge Club-houses, the Lyceum, St. James's, and Olympic Theatres (the first two were completed in sixteen and ten weeks respectively), the Nelson Column, all the Great Western Railway works between Hanwell and Langley (including the Hanwell Viaduct, but

excluding the embankment), a large part of the South-Eastern Railway, and the Woolwich Graving Dock. It was during the construction of the railway works above mentioned that Mr. Grissell and Sir M. Peto severed partnership, the former retaining the building contracts, including the contract for the Houses of Parliament, which had been commenced by the firm, and Sir Morton retaining the railway contracts. Differences arose concerning the payment for the Hanwell Viaduct:—the contract provided for arbitration or reference to the Engineer-in-Chief. Sir Morton chose the latter course; he met Mr. Brunel evening after evening after dinner, and all the accounts were gone through together, and after a twelvemonth the latter certified the sum claimed, £162,000, to be correct, but the firm had had to borrow £100,000 to carry on the works. Among the works taken over single-handed by Sir Morton was a large portion of the South-Eastern Railway, that between Folkestone and Hythe, including the viaduct and tunnel, and the Martello Towers; the late Mr. E. L. Betts, Sir Morton's subsequent partner, had undertaken the construction of the railway between Reigate and Folkestone. Sir Morton also alone constructed large portions of the then Eastern Counties Railway between Wymondham and Dereham, Ely and Peterborough, Chatteris and St. Ives, Norwich and Brandon; also the sections between London and Cambridge, Cambridge and Ely, the Dorsetshire portion of the London and South-Western Railway, and the works in connection with the improvement of the Severn navigation, under Sir William Cubitt. The memoir of Mr. E. L. Betts, published in 1872-3, enumerates the works undertaken by the firm Peto and Betts.[1] They embraced the loop-line of the Great Northern Railway, from Peterborough through Lincolnshire to Doncaster; the East Lincolnshire line, connecting Boston with Louth; the Oxford, Worcester, and Wolverhampton Railway; the first section of the Buenos Ayres Great Southern Railway, the Dunaberg and Witepsk Railway; the line between Blidah and Algiers, and the boulevards with warehouses underneath at the latter place; the Oxford and Birmingham Railway (including the Harbury cutting); the Hereford, Ross, and Gloucester Railway; the South London and Crystal Palace Railway; the East Suffolk section of the Great Eastern Railway; the Victoria Docks (London); the Norwegian Grand Trunk Railway (between Christiania and Eidsvold), and the Thames Graving Docks.

In connection with Mr. Brassey and Mr. Betts were executed

[1] Minutes of Proceedings Inst. C.E., vol. xxxvi. p. 286.

lines of railway in Australia, the Grand Trunk Railway of Canada (including the Victoria Bridge), the Canada Works (Birkenhead), the Jutland and Schleswig lines (under Mr. Bidder, Past President Inst. C.E.), the railway between Lyons and Avignon, and the Tilbury and Southend Railway. Sir Morton Peto, Mr. Betts, and Mr. Crampton were in partnership in carrying out the contracts of the Rustchuk and Varna Railway and the Metropolitan extensions of the London, Chatham and Dover Railway; Messrs. Peto and Betts constructed the portion between Strood and the Elephant and Castle. Sir M. Peto subsequently negotiated, without success, for works in connection with the improvement of the Danube navigation, and for railway works in Portugal. His last railway contract was one for the construction of the Cornwall Mineral Railways. From 1847 to 1853 Sir Morton sat in Parliament for Norwich; from 1859 to 1863 for Finsbury, and from 1865 to 1868 for Bristol. During the first period he aided in starting the Great Exhibition of 1851, by offering a guarantee of £50,000 in its support, and was subsequently one of Her Majesty's Commissioners. During the Crimean War, the difficulty experienced in providing the troops with food and clothing led him to suggest to Lord Palmerston the construction of a railway between Balaclava and the entrenchments. The Duke of Newcastle, the then Secretary for War, adopted the proposal, and a line of 39 miles in length was laid down, which proved of much service to the expedition. The little army of navvies was admirably provided for, and the death-rate among them was less than the death-rate in London for the same period. The firm of Peto and Betts presented vouchers for every item of expenditure, and received payment without commission. The contract being under Government, though without profit, obliged Sir Morton to resign his seat in Parliament, and he subsequently had the baronetcy conferred for the services thus rendered by his firm. After Sir Morton's retirement from Parliament, he lived principally at Eastcote House, Pinner, and subsequently at Blackhurst, Tunbridge Wells, where he died on the 13th of November, 1889. Sir Morton's career is interesting, not only from the vast amount of work achieved by one man, but as recalling the leading civil engineers of the first half of this century, and most of whom had been, or subsequently became, Presidents of the Institution. His genial manners procured him their friendship, and won for him the affectionate regard of his agents. He was wont to speak with pleasure of the confidence Mr. George Stephenson gave him. An incident in the construction of the Eastern Counties Railway led to the trust Stephenson implicitly put in the contractor.

Stephenson had expressed his dissatisfaction at a wooden bridge which had been erected. The contracts did not then minutely specify the works as they now do. Sir Morton, on his own authority, adopted a drawing from the office, and an iron bridge was substituted. Stephenson expressed his surprise, and said he had not ordered it; but on the contractor's reminding him that he was bound to execute the work to the satisfaction of his chief, and that he had had his previous dissatisfaction in mind, Stephenson expressed his pleasure, and thus commenced a friendship which lasted till the great engineer's death.

Sir Morton Peto was a member of the Baptist denomination, and benefited the same by providing the funds for the erection of Bloomsbury and Regent's Park Chapels; but his was no narrow mind, and his catholicity was shown when he restored the parish church on his estate at Somerleyton, and his liberal creed was acknowledged by a Clergyman and a Nonconformist minister joining in performing the burial service at his grave—a not unfitting testimony to the spirit of the author of the Burials Bill. Sir Morton's large nature was exhibited in the manner he bore his misfortunes, which disappointed his hopes of retiring from business and continuing his parliamentary career. He was never known to brood over the past; but to the last was employed in charitable work in connection with his denomination and as one of the trustees of Lady Hewley's Charity, and nothing gave him more pleasure than being instrumental in starting young men in their career, especially when in connection with engineering works. Just before his retirement, Lord Beaconsfield (then Mr. Disraeli) paid a tribute to his character, saying he had recognized with admiration his enterprise and energy, and added "the House must also sympathise with an Hon. Member who has sat among us for so many years, and who has shown so many high qualities which entitle him to our respect." Mr. Gladstone echoed the tribute paid to the Hon. Member for Bristol: "A man who has attained a high position in this country, by the exercise of rare talents, and who has adorned that position by his great virtues."

Sir Morton Peto was elected an Associate of the Institution on the 26th of February, 1839.

EDWARD CROFT GREENWAY THOMAS was an Indian civil servant, who, deeply impressed with the conviction that extensive engineering works, constructed and maintained by Government, could alone cope with the evils of constantly recurring famines,

devoted much of his time and resources to the acquisition and diffusion of exact information on this all-important subject. He joined the Indian service on the 17th of September, 1851, and after passing the prescribed examinations in Telegu and Tamil, was posted as assistant to the collector and magistrate of Coimbatore. Thence he rose steadily and continuously until, on the 27th of August, 1869, he was appointed judge of Vizagapatam, on the Malabar Coast. He occupied this position for thirteen years, and threw himself heart and soul into a scheme for creating a large harbour at Vizagapatam, and constituting it the port for the Central Provinces of India. Taking for his text the axiom, "Nature is always at work, and man's mission is to turn her powers to his own account," he urged that it was the duty of the Government to regulate the Indian rivers, in their upper portions, where they were still amenable to gentle means, so as to prevent their beds from becoming the depositories of furious torrents during three months of the year, and vast stretches of burning sand during the remainder. By statistics he showed that famines were becoming more and more frequent, and were directly traceable to the neglect of replanting the forests on the mountain slopes. Briefly, his proposed remedy was this:—Plant trees wherever they can be got to grow, but plant systematically. Where the river is young, *i.e.* where it is born in the mountains, its bed should be thickly planted. As the river descends in its course the trees should be at less intervals, till at last, where it becomes navigable, a clear channel in the middle should be left unimpeded, while the rest of the bed, which in many Indian rivers may be more than a mile wide, and also the banks, should be thickly planted. By this means not only would the monsoon water be retained in the river bed over a much longer period, but, the rains being much more frequent, would cause the flow to be perennial, and the climate would be greatly benefited. Also cheap irrigation channels could be constructed, so as to allow of certain crops being produced over regions that are now barren, and the whole country could be intersected by canals which would convey produce in the most economical manner. As a proof of this he instanced the native boat used on existing Malabar canals. "Perhaps the most economical application of power in the conveyance of goods in the world is that which is to be seen in the canals of Malabar. There a tree, 60 feet long, and 2½ feet in diameter, is hollowed into a canoe, the opening above not wider than a plank would cover; this canoe will carry with ease much more than 6 tons of grain, it floats in the water like a duck, requires little depth and little width. A boy sits at the helm steering, and a

man propels it by walking along the plank with a punting-pole against his chest. This man and the boy take this boat containing twelve ordinary cartloads of grain, 30 miles in the twenty-four hours. Thus for 6 annas (9*d.*), doing three days' work of twelve carts with their pairs of bullocks and their drivers."[1] Mr. Thomas estimated that in the flat country around Vizagapatam, such channels 6 feet wide, and 2 feet deep, could be constructed for Rs. 240 a mile. His enthusiasm induced him to urge these views, perhaps with more persistence than discretion. He claimed for them that they were those of a public servant of twenty-six years' service over seven districts, an Anglo-Indian in feeling from his birth (a feeling not unnaturally inherited from two previous generations who had spent their heartiest energies, and the greatest part of their lives in the Civil Service of India), and one intimately acquainted with the natives, and desirous of benefiting both them and their rulers. There can be no doubt of the sincerity of his motives.

In 1881 Mr. Thomas retired from the Indian Civil Service and came to reside in England, devoting the greater part of his time to the development of a form of floating breakwater, which he believed would prove of great value in securing quiet water off seaports and river estuaries, if he could once get its merits practically tested. He lacked the engineers' knowledge of construction and constructive details, and although he worked with untiring energy, and occasionally sought the assistance of engineers, he overlooked the importance of essential details in his eagerness to get the principle tested. After his return to England he may be said to have devoted his life to amateur engineering and inventing. In the latter somewhat unpromising field he appears to have found considerable delectation, for in less than seven years he took out thirteen patents ranging over a variety of subjects, from breakwaters and harbours to door-handles, from armour-plating to table implements for holding asparagus! He was also the author of the work on Vizagapatam previously referred to, and of one entitled "Famine, and other Indian Topics," published at Madras, and of various contributions to the engineering press.

Mr. Thomas died on the 13th of September, 1889. He was elected an Associate of the Institution on the 1st of December, 1885.

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[1] "Vizagapatam; the Port for the Central Provinces." By E. C. G. Thomas. Folio plates and photographs. Madras, 1877.

*** The following deaths have been made known, since the 30th of September, besides some of those included in the foregoing notices:—

Honorary Members.

FROME, *General* EDWARD CHARLES, R.E.; *born* 7 January, 1802; *died* 12 February, 1890.

H. M. DOM LUIS I., King of Portugal; *born* 31 October, 1838; *died* 19 October, 1889.

Members.

ADAMSON, DANIEL; *born* 1818; *died* 13 January, 1890.

ATKINSON CHARLES ROBERT; *died* 13 December, 1889.

BREBNER, ALAN; *died* 5 March, 1890, *aged* 64.

CONDER, FRANCIS ROUBILIAC; *born* 26 November, 1815; *died* 18 December, 1889.

FRASER, HENRY JOHN; *born* 20 March, 1848; *died* 13 October, 1889.

GAMBLE, JOHN GEORGE; *born* 22 January, 1842; *died* 7 November, 1889.

GORDON, JOSEPH; *born* 16 April, 1837; *died* 9 November, 1889.

HETHERINGTON, THOMAS RIDLEY; *born* 5 April, 1835; *died* 10 December, 1889.

JOPLING, FREDERICK; *born* 5 November, 1855; *died* 17 February, 1890.

LEDGER, JAMES CAMPBELL; *born* 25 March, 1833; *died* 23 November, 1889.

LESLIE, JAMES; *born* 25 September, 1801; *died* 29 December, 1889.

LUNN, ROBERT WATSON; *died* 13 March, 1890, *aged* 75.

MCALPINE, WILLIAM JARVIS; *born* 1812; *died* 16 February, 1890.

PENNY, ALFRED; *died* 4 March, 1890, *aged* 79.

RING, ROBERT; *born* 29 September, 1847; *died* 2 January, 1890.

RUNDLE, CUBITT SPARKHALL; *died* 24 December, 1889, *aged* 70.

STANDFIELD, JOHN; *born* 23 July, 1838; *died* 2 March, 1890.

STEEL, WILLIAM HERON; *born* 13 March, 1830; *died* 25 December, 1889.

VIGNOLES, HUTTON; *born* 18 November, 1824; *died* 14 December, 1889.

WRIGHT, GEORGE HUSTWAIT; *died* 11 December, 1889, *aged* 55.

Associate Members.

ARCHBOULD, RALPH; *born* 25 September, 1856; *died* 5 December, 1889.

BIBRA, CHARLES FREDERICK VON; *born* 15 November, 1844; *died* 1 April, 1889.

BUARQUE, ANTONIO LUPICINIO; *born* 21 March, 1854; *died* 31 August, 1888.

CHITTENDEN, FRANCIS SHELDON; *died* 11 January, 1890, *aged* 44.

HACKNEY, WILLIAM; *died* 4 February, 1890, *aged* 48.

HAGHE, AUGUSTUS; *born* 25 May, 1846; *died* 5 February, 1890.

HAWKES, EDWARD CLAUDE; *born* 29 December, 1845; *died* 14 February, 1890.

JACKSON, EDWARD RAINFORD; *born* 28 April, 1860; *died* 13 July, 1889.

SALMOND, JOHN MITCHELL; *born* 27 May, 1842; *died* 1889.

SOARES, PLOTINO; *born* 9 July, 1850; *died* October, 1889.

Associates.

ANDERSON, RICHARD; *died* 26 January, 1889.

BARRY, WILLIAM HENRY; *born* 2 October, 1824; *died* 15 January, 1890.

BEAUCHAMP, *Lt.-Col.* CLAYTON SCUDAMORE, *late* R.E.; *born* 24 April, 1842; *died* March, 1889.

MOORE, WILLIAM WEBB; *died* 1 September, 1889.

PARKER, *Major* FRANCIS GEORGE SHIRECLIFFE; *born* 1836; *died* 28 February, 1890.

WALKER, THOMAS ANDREW; *died* 25 November, 1889, *aged* 61.

WEBB, *Major* THEODOSIUS, R.E.; *born* 28 November, 1817; *died* 17 December, 1889.

Information respecting the life and works of any of the above is solicited.—SEC. INST. C.E., 31 *March*, 1890.

Sect. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

Bing's Set Square.

(Schweizerische Bauzeitung, vol. xiv., 1889, p. 115.)

Mr. E. Bing, Director of the wagon works in Riga, has invented a set square, the angles of which are not 30° and 60° as usual, but 27° 35′ 50″, and 62° 24′ 10″. The cosine of the smaller angle is thus $\sqrt{\frac{\pi}{4}}$, and if in a circle a diameter d be drawn parallel to the hypotenuse, and from one end of the diameter a chord be drawn parallel to the longer side of the set square, the length of the chord is $d\sqrt{\frac{\pi}{4}}$. The chord of the circle is therefore the side of a square having an equal surface with the circle. A perpendicular from the upper end of the chord to the diameter cuts off on the latter a length equal to one-fourth of the circumference of the circle.

G. K.

Examination of a Volcanic Sand as a Material for Mortar.

By Dr. Böhme.

(Mittheilungen aus den Königlichen technischen Versuchsanstalten zu Berlin, Supplement I, 1889.)

The sand with which these experiments were made is found in large quantities in the Eifel mountains, in Germany, and appears to have been ejected from the now extinct volcanoes in that district. Locally, it is used as a binding material for the surface of roads; but the cost of transport prevents its use for this purpose, except in the immediate neighbourhood of the deposits. It has for some time been known that this sand, in conjunction with lime, gives a good hydraulic mortar, and the experiments described in this Paper were undertaken chiefly with a view to testing it in this direction.

Two kinds of the sand were examined, one coarse and the other fine. Their chemical composition differed but little. The percentage of silica was about 52, of alumina 14, of lime 11, and of magnesia 7.

These sands were compared with the Prussian standard sand, which passes through a sieve of 60 meshes per square centimetre (387 meshes per square inch), and is caught upon one of 120 meshes per square centimetre (774 meshes per square inch). The fine volcanic sand left a residue of 25 per cent. upon the 60-mesh (387 meshes per square inch) sieve, and the coarse of 33 per cent., while the residue upon the 120-mesh (774 meshes per square inch) sieve, was 39 per cent. and 41 per cent. respectively.

The weight of a litre (1·76 pint), when shaken down, was 1·640 kilogram (3·6 lbs.) for the standard sand; 1·997 kilogram (4·4 lbs.) for the fine volcanic sand; and 2·039 kilograms (4·495 lbs.) for the coarse volcanic sand.

The volcanic sand mortar was compared with mortars made of Portland cement, two varieties of lime and pulverised trass. Some briquettes were allowed to harden exposed to the air, others under water. From these materials, forty-two different varieties of mortar were made, and the results of the tests carried out with them are given in numerous Tables.

Except when it was used in conjunction with Portland cement, the results obtained with the coarse volcanic sand were almost identical with those from the fine sand. As compared with the standard sand, it was found that in every case the volcanic sand gave a higher tensile and crushing strength; the increase in many cases being very considerable. For instance, a mortar composed of 1 part of Portland cement with 3 parts of standard sand gave a tensile strength of 34·15 kilograms per square centimetre (485·71 lbs. per square inch) when immersed in water for one year, while a similar mortar, made with fine volcanic sand, attained a strength of 50·15 kilograms per square centimetre (713·28 lbs. per square inch) in the same time. The crushing strength of the same mortars under similar conditions was 320·8 kilograms per square centimetre (4,562·66 lbs. per square inch), and 499·1 kilograms per square centimetre (7098·58 lbs. per square inch) respectively.

Mixtures of different varieties of rich lime and volcanic sand were also far superior in strength to similar mortars made with standard sand, especially when the briquettes hardened in the air.

With high proportions of sand, the influence of the volcanic sand was more marked, both for cement- and lime-mortars. The tensile strength of a mortar composed of 1 part of Portland cement and 40 parts of standard sand was 0·34 kilogram per square centimetre (4·836 lbs. per square inch) in the air in twenty-eight days. When volcanic sand was substituted for standard sand, the strength rose to 3·63 kilograms per square centimetre (51·63 lbs. per square inch). One part of rich lime mixed with 40 parts of standard sand gave a tensile strength of 0·53 kilogram per square centimetre (7·538 lbs. per square inch) in the air in twenty-eight days, while with volcanic sand in the same proportions and under the same conditions the strength was 4·99 kilograms per square centimetre (70·97 lbs. per square inch).

Experiments were made to ascertain the adhesion of mortars made with volcanic sand to stone when used as a plaster, and their resistance to frost was also tested. In both cases the results were highly favourable to the new material.

W. F. R.

New Apparatus for Testing Materials in Tension and Compression. By H. BONNAMI.

(Le Génie Civil, vol. xv., 1889, p. 475.)

The results of experiments obtained by different operators frequently differ very widely indeed, on account of their not working under identical conditions. The desirability of having a machine at once simple, accurate, and automatic, to facilitate such operations is obvious. Mr. Buignet, of Havre, has succeeded in producing such a machine, suitable for testing Portland cement, in a very simple and ingenious manner.

His apparatus consists essentially of two vertical tubes, the one being rigid and the other flexible. The latter terminating in a reservoir provided with an escape-valve. Both tubes are connected to a pan, closed above by an india-rubber diaphragm. The tubes and pan are filled up to a datum line with some suitable liquid, preferably mercury; the space between the mercury and the diaphragm is filled with water.

On raising the reservoir, no pressure is exerted on the diaphragm if the escape-valve be closed; care being taken that the height of the reservoir above the datum never exceeds 760 millimetres (29·92 inches). On opening the valve, the mercury slowly escapes, and exerts a pressure on the diaphragm in virtue of its height in the rigid tube, to which it is proportional.

The whole of the apparatus is mounted on a cast-iron stand. The pan, which is a part of the same casting, has two cavities; one is in communication with the rigid tube, and the other with the flexible tube and reservoir. The upper part of the flexible diaphragm is covered by a brass disk, on which a bent standard is pivoted; one of the pulling clips is suspended from the upper part of this standard, and the other clip is provided with an adjusting screw for bringing the clips up to their work when the briquette is inserted.

The load on the briquette is measured by the height of the mercury column in the rigid tube. The height being indicated and registered by means of a float, a string attached to it passes over a ratchet-pulley, and is kept tight by a balance-weight on the other end. The ratchet allows the index to rise, but not to fall, unless the pawl is released. The reservoir valve is provided with a divided disk to indicate the amount of opening, and consequently the rate at which the load is applied to the briquette. The reservoir itself slides up and down a guide pillar; on reaching

the top it is held in position by a catch. The *modus operandi* is as follows:—The briquette having been inserted in the clips and screwed up, the reservoir is raised and the valve opened, when the mercury gradually rises in the fixed tube, and applies the load on the specimen until fracture occurs. The mercury suddenly falls, but leaves the index in its highest position, thus indicating the breaking-stress in kilograms per square centimetre on the fractured area.

By a slight modification, the apparatus may be adapted for compression as well as tension tests.

J. G.

Stresses in Bridges. By WILLIAM H. BOOTH, M. Am. Soc. C.E.

(Transactions of the American Society of Civil Engineers, 1889, p. 137.)

Commenting upon the character of modern bridge specifications, and upon the views that have recently found favour with bridge engineers, the Author remarks that the general tendency of American, and of the best English practice, is towards a more accurate determination of the actual effects of loading, and concurrently towards a reduction of the so-called Factor of Safety by eliminating that portion of it which has been used merely to cover the known imperfections of previous methods.

If this line of progress could be followed to its proper results, it would leave a very moderate factor (not much greater than unity), which might then be consistently termed the Factor of Safety; but the practical difficulties standing in the way of such an improvement are considerable, and they arise chiefly from ignorance of the actual stresses caused by a moving load. The old practice of allowing a uniform working stress has already been discarded, and it is fully recognized that members which are subject to a suddenly-applied load must be calculated as for a static load of much greater magnitude; but to ascertain the true percentage of increased stress due to a rapidly-moving train, or to the unbalanced masses of the engine mechanism, appears to be a difficult problem.

A little consideration shows that the dynamic effect of the load depends not only upon the load itself, but also upon questions connected with the structure of the bridge, such as its deflection and the deflection of its constituent parts; and it depends also upon the mutual relations between the bridge and its moving load, such as the relation between the velocity of train and the period of vibration of the bridge, or the relation between the panel length and the circumference of the driving-wheel; and also upon the more complex relations between all of these matters taken together.

The above-mentioned causes contribute in various degrees to augment the stress due to a moving load; and therefore, when the stresses are calculated upon statical principles only, the bridge is generally designed with a very low-working stress, such as

10,000 lbs. per square inch. It is known that the material is perfectly capable of bearing safely a repeated stress of perhaps 20,000 lbs., but the engineer dares not approach this limit, because he knows that the calculated stresses are liable to be greatly increased; and if it were once realized that the nominal stress of 10,000 lbs. is actually and daily increased to 15,000 or 20,000 lbs. by the operation of the above-named causes, it would soon become the practice to allow in all cases for the real internal stress that takes effect upon the material, and not merely for the nominal stress calculated on the principles of statics.

It seems desirable, therefore, that the strength of bridges should be determined by reference to the actual, and not the nominal stresses; and if such a rational method were compared, in its results, with the older one, there would be found a great difference in the case of long-span bridges, where the load is chiefly a dead load; and the conclusion would result that either large bridges are generally made stronger than they need be, or else that small bridges are much weaker than they should be.

With the view of tracing out the total effects of the moving load, the Author begins with the vertical action of the unbalanced masses and counterweights of a driving axle, and assuming a high speed of train, he finds the amount to be a serious one in the case of small driving-wheels. Then, adding this amount to the nominal load on the wheel, he goes on to inquire what stresses will be produced in the elastic bridge by the sudden application of this augmented load.

The trajectory of the wheel when moving across the elastic bridge is considered in an elementary manner, and the Paper aims at the discovery of some practical rules for determining approximately the percentage of the dynamic effect on bridges of different spans. The same question is then considered in its relation to the stringers and floor-beams, and the component members of the main truss; and in this connection the Author takes account of the lateral swaying of the engine, and the effect of wind in transferring load to the leeward truss.

The Paper also treats of the cumulative vibrations observed by Professor Robinson, and due to the fortuitous coincidence of the panel length with the wheel spacing of the train or with some multiple of it, or due to the coincidence of the panel length with the circumference of the driving-wheels; and points out the difficulty of avoiding these coincidences by any possible choice of panel length.

The Author recommends the experimental measurement of the dynamic increment by observations of the momentary deflection of bridges, the adoption of deep trusses and rigid floor-beams and stringers, and the counterbalancing of locomotive gear in a vertical direction.

T. C. F.

Some Experiments on the Strength of Bessemer-Steel Bridge Compression members. By JAMES G. DAGRON.

(Transactions of the American Society of Civil Engineers, vol. xx. 1889, p. 269.)

The lack of data as to steel in compression led to these experiments with eight columns, made of two plates with two angle-irons each, pointing outward, and braced together by two sets of single triangular flat bar bracing of $\frac{1}{4}$ and $\frac{5}{16}$ inch in thickness. The distance between pins was from 16 feet to 25 feet $7\frac{1}{2}$ inches, and the ratio of length to radius of gyration, from 42·05 to 63·075.

The formula for the permissible pressure per square inch which had to be complied with, was—

$$\frac{11{,}000}{1 + \frac{1}{18{,}000}\left(\frac{l}{r}\right)^2} \text{ lbs.,}$$

$\frac{l}{r}$ being the abovenamed ratio.

The experiments were made to show how much greater than 11,000 the numerator in the formula would be at the point of collapse of the columns.

The result varied from 41,650 lbs. in the 16-feet columns, to 35,570 in the 25 feet $7\frac{1}{2}$ inches columns.

Considering that experiments with wrought-iron columns have led to the adoption of 40,000 lbs. for the numerator in the formula, the experiments show that the strength of steel columns is not greater than that of iron, in the proportion of the strength of the materials (but rather in proportion of their moduli of elasticity, as might have been expected).

The engravings of the damaged part of the columns, on a large scale, are particularly instructive.

M. A. E.

Cement Tubes for the Cuneo Aqueduct. By G. PONZO.

(L'Ingegneria civile e le Arti industriali, 1889, p. 125.)

The Author, in describing the works carried out under his supervision in connection with the water-supply of the city of Cuneo, refers to the increasing importance of cement in engineering works, on account of its adaptability to the construction of large tubes for drainage or sewerage purposes, or of smaller tubes for water-supply, and its capacity to resist great pressure. It is advantageous in the matter of economy, of rapidity of construction, of impermeability, and of facility of adaptation to any form. In the climate of Italy its usefulness is also greatly enhanced by the high degree in which it preserves the freshness and purity of the

water, a most important matter in the supply of drinking-water, where there is any special liability to cholera or other endemic diseases. The cost of cement tubes is not more than about 40 per cent. of that of iron pipes.

The work carried out for the municipality of Cuneo consisted in the extension of their supply, in order to provide the newer and higher parts of the city with a sufficient quantity and pressure of water. The old supply is conveyed in an open channel through a tunnel or subway, 5 feet 11 inches in height, to the crown of the arch, and 2 feet 3½ inches in width. This tunnel is made use of for the main length of the new pipes, which are laid on the floor-level and over the original channel, which is arched over by the new work. The lower channel is retained for all general purposes—street-watering, baths, washhouses, &c., while the new cement-tube conveys the water for drinking purposes. There is a fall of 77·8 feet in a length of 1,973 yards, the average inclination being, therefore, about 1 in 76. The new supply having to be under the full pressure due to this total fall, the Author, before commencing the work, undertook various experiments to determine the proportions to be given to the tube. According to the usual formula, the tube, having a diameter of 9⅞ inches, with head of water as above, would require a thickness of 7½ inches; but, by a series of careful experiments, it was found that a thickness of 3·15 inches was amply sufficient. The material employed was Casale cement, and the cost (including labour) was found to be about 5*s.* per lineal yard. Inclusive of all contingent charges, the cost of the work as executed was 6*s.* 9*d.* per yard. Owing to the confined space in which the work had to be carried out, advantage was taken of four manhole shafts to start work simultaneously from all the different faces, and the materials were conveyed along the tunnel on small trollies. The work was entirely completed without interference with the old supply in the open channel. The cement was set over this channel on a curved iron plate, which served as a centering until the material set, while the sides were moulded between larch frames wedged as necessary. The core consisted of an expanding iron cylinder. Each mixing of material, which was done on the spot, made sufficient for a length of 6 feet 6 inches. During the winter the cement set in twelve hours, but later, when two qualities of cement were blended, the setting was perfect in less than seven hours.

P. W. B.

The Bridge over the Arkansas River at Van Buren.

By C. D. Purdon.

(Transactions of the American Society of Civil Engineers, vol. xx. 1889, p. 151.)

This bridge has a total length of 1,798 feet, consisting of three spans 252 feet 9 inches each, four spans of 162 feet each, and a swing-bridge 366 feet long. The main girders are of the American

pin type, but the top chords rise towards the centre, and thus resemble the double-span girder of the swing-bridge. The bridge has a single line of railway, the platform resting on six longitudinal stringers, of which the two outer ones do not carry the train in its usual position.

The Paper gives a full account of the history of the erection of the bridge, weights and quantities of materials, and the specification for the contract of the work, which is as complete as American specifications now usually are.

M. A. E.

The Sibley Bridge.

By O. Chanute, J. F. Wallace, and W. H. Breithaupt.

(Transactions of the American Society of Civil Engineers, vol. xxi. 1889, p. 97.)

For the purpose of extending the railway from Kansas City to Chicago, the crossing of the Missouri could be effected in a direct way at Sibley Point, or in a north and south direction at Sibley Reef, lengthening the line by 1 mile. The latter point, however, was chosen on account of a lesser probability of a change in the bed of the river, on account of a smaller width of the river by 550 feet, and on account of a greater height of the bed rock by about 10 feet, viz., 30 to 40 feet below low water.

The bridge is 2,000 feet long, in seven spans, as follows: 200, 400, 400, 400, 250, 175, 175. The 400-feet spans are over the river, giving a clear height of 50 feet above the high-water mark of 1844, the railway being on the bottom flange. In the other spans the railway is on the top flange of the girders (deck-spans). The piers are of limestone masonry, the base of the largest being 63 feet 9 inches × 27 feet 5 inches, with a pressure of 7,600 lbs. per square foot on the rock from all loads. The foundations of the piers between the second and the seventh span were made with the pneumatic method; the sinking of the timber caissons began on March 23, 1887, and the last pier was completed on December 15 of the same year. The erection of the iron superstructure, for which the contract was let to the Edgemoor Iron Company on January 15, 1887, began on July 27, 1887, and was completed on February 11, 1888.

The 400-feet span girders are of the familiar American pin type, composed of riveted top chords, posts and struts, and of forged bottom chords and diagonals (eye-bars). The diagonals are inclined at an angle of about 45°, intersecting the posts in the middle; the depth of the girders is 50 feet between pins and the panel—length 24 feet 9 inches. The width between centres of trusses is 21 feet for a single line of railway. Besides the ordinary rail-bearers directly under the rails, and calculated with the full load, there is a second pair 9 feet 2 inches apart, calculated with

half the load. The sleepers are 16 feet × 8 inches × 8 inches, and are spaced 14 inches between centres. There is an inner iron guard-rail, and an outer oak rail protected by an angle-bar. The top chords, including the rivets, the bottom chords and the diagonals are of steel; the intermediate posts and struts are of iron. The quantity of steel in each 400-feet span is 718,751 lbs., and the quantity of iron 513,947 lbs.; the weight of timber floor with rails is 480 lbs. per foot lineal.

The moving load consists of two Consolidation engines of 172,000 lbs. each, on a base of 55-feet length, followed by a train of 3,000 lbs. per lineal foot.

The wind pressure is taken at 30 lbs. with the train-load and 50 lbs. without it; in both cases two surfaces of one truss have been calculated. In proportioning the sections the Launhardt formula

$$s\left(1 + \frac{1}{2}\,\frac{\text{minimum stress in member}}{\text{maximum stress in member}}\right)$$

was used for the 400-feet spans, but not for the smaller spans. For the steel bottom chords s was assumed = 12,000 lbs. for stresses from the load, and = 15,000 lbs. for stresses from wind-pressure. For riveted members in tension s was taken one-seventh less. For compression members, s = 10,000 lbs. for steel end-posts and top-chords, 8,000 lbs. for iron intermediate posts, and 12,000 lbs. for iron struts, multiplied, however, with the factor as above, and then put into the formula—

$$\text{permissible strain per square inch} = \frac{s}{1 + \dfrac{l^2}{a\,r^2}}$$

where a = 40,000 for columns with two flat ends, a = 30,000 for columns with one flat end, and a = 20,000 for columns with two pin ends. Flanges of floor girders 6,000 lbs. per square inch, webs 4,000 lbs. per square inch, rivets and pins in shear 7,000 lbs. per square inch, rivets in situ and in floor-beams 5,600 lbs. The bearing area of pins and rivets to be proportioned to 12,000 lbs. per square inch, and the bending strain in pins not to exceed 15,000 lbs. on iron and 20,000 lbs. on steel. The pressure on the granite bed-stones not to exceed 250 lbs. per square inch = about 16 tons English per feet superficial. The pressure on the longitudinal inch of expansion rollers of d inches diameter not to exceed $\sqrt{540{,}000d}$ lbs.

These data are followed by a specification of materials, and by an account of tensile and compressive tests.

The Paper is illustrated by fourteen plates, and several wood-cuts.

M. A. E.

Partial Destruction of the Jeetzel Bridge by Flood and its Restoration. By M. Boettcher.

(Zeitschrift für Bauwesen, Berlin, p. 287, 1889.)

The bridge in question carries the Wittenberge and Lüneburg railway between the stations of Dannenberg and Hitzacker, over the River Jeetzel, near the junction of the latter with the Elbe. The bridge was constructed for a double line, with three spans of girders on the Schwedler system, each opening being 107 feet 3 inches in the clear, with girders 110 feet 3 inches long, the weight of ironwork in each span being 88 tons, inclusive of flooring and permanent-way.

The two piers are 41 feet long, and 7 feet 3 inches broad, each being founded on two semicircular wells of 15 feet 9 inches in length, and 10 feet 2 inches in breadth, sunk to a depth of 13 feet 6 inches, the intervening space being spanned by an arch on which rests the centre portion of the pier. The foundations of the wells were carried down for several feet into a stratum of medium coarse sand, but were not protected in any special manner. The land abutments were laid on the sand and protected from scour by sheet piling.

The bridge, erected in 1872–73, withstood the effects of heavy floods until the spring of 1888, when, owing to an ice-dam being formed in the Elbe above the junction of the Jeetzel, the flood burst the banks of the former river at several places near Dannenberg, and flooding the low-lying intermediate district passed into the Jeetzel, and as the railway embankment remained intact, the whole volume of water finding its way again to the Elbe, had necessarily to pass entirely by the bridge-way in question.

The scour caused by these abnormal conditions led to a subsidence of the pier nearest Hitzacker, the foundation wells sinking alternately, namely, first that at the up-stream end of pier, then the down-stream, then again the up-stream, and lastly, that at the down-stream end. The total settlement amounted, at the down-stream end, to 10 feet 6 inches, and at the up-stream end, to 9 feet 10 inches.

In addition to this subsidence, the pier was turned on its axis, so that the down-stream end was brought 10 inches nearer the Dannenberg bank; also the pier was tilted out of the perpendicular across and down-streamwards, to the extent of 1 inch and 5 inches respectively, in a height of 22 feet.

The other pier and the abutments, although subjected to great scour, were not affected in level.

Diagrams are given, showing the bridge, &c., and a cross-section of the river-bed before and after the flood, also a view of the bridge with the sunken pier. As regards the ironwork but little damage was caused beyond the displacement of the hinged bed-plates. On investigation by borings of the river-bed as deepened, it was found that the stratum was of sufficient density to support

the extra weight of masonry required in heightening the pier to its former level; also it was found, on examination by an experienced diver, that the pier, wells, and arch were in no way dislocated, and consequently could be used as a base for the new work, the first procedure being to surround the base with ballast to a height of 10 feet above the stream bed, and forming at the top a bench of 6 feet 6 inches in breadth.

A detailed description is given of the method adopted of gradually raising in successive stages the girders and flooring, by means of hydraulic (glycerine) jacks of 20 tons lift, the masonry being carried up simultaneously. Four jacks, each worked by two men, were used in lifting each span to be raised, viz., two to each girder end, being bound to the lower boom of the girder ends by wrought-iron rods of 1 inch in diameter, and resting on half-round oak-sleepers serving as rockers, to allow of the alteration in the direction of the axes of the jacks during each lift of from 14 to 16 inches. For distributing the pressure on the masonry, and at the same time packing up the superstructure during each lift, oak slabs were used. The masonry immediately under the bearings of the jacks was laid in quick-setting cement. The girders of the two spans affected were thus raised alternately, an interval of from twenty to twenty-four hours being allowed between the successive lifts for the setting of the cement. To prevent a forward movement of the girders while being lifted, especially during the early stages of the work, when the inclination was considerable, each superstructure was held in check by chains controlled by four crab-winches anchored on the bank, and also strutted against the lower part of the pier. After the girders had been raised to their intended permanent level, they had to be shifted laterally, the one to the extent of 2½ inches, and the other 6⅝ inches, which was effected by sliding them on ways smeared with soft-soap, the necessary longitudinal adjustment being made in a somewhat similar manner by tilting the superstructure at one end by jacking-up until movement ensued; during this process, however, there occurred on one occasion an unexpected lateral lurch, causing a breakage of the jacks. After the superstructures were got into their ultimate positions, all that remained to be done, was to replace a few of the wind-pressure floor-diagonals, and complete the bridge-floor over the piers. The above-described work was completed, and the bridge re-opened for traffic on the 28th of August, 1888, the lifting of the superstructure having been commenced on the previous 23rd of June.

The cost of the raising of the superstructure and masonry, including the material and making good the permanent-way, amounted to about £592 10*s.*

D. G.

The Oisilly Viaduct.

(Compte rendus de la Société des Ingénieurs-civils, June, 1889, p. 953.)

This viaduct over the valley of the Vingeanne, not far from Dijon, carries a railway to Gray on the Eastern Railway of France, and was opened in October 1888. The masonry structure has a total length of 964 feet, and consists of seven elliptical arches, springing from a point 3 feet 7 inches above ground-level, and having a clear span of 121 feet 5 inches, with a rise of 47 feet 6 inches. The width of the present structure is 14 feet 9 inches, but the foundations are built to receive a double line. The width at the piers is 22 feet 6 inches including counterforts. The thickness of the arch proper is 4 feet 3 inches at the crown and 7 feet 10 inches at the point of junction with the adjoining arch. In the spandrils of the arches are three small arches of 8 feet span. The centering for each arch consisted of four principals, of which the lower part was fixed and the upper movable. Between the two parts were placed the sand-boxes, used for lowering the upper part. The settlements of the seven stone arches were found to range between ½ and 4 millimetres. No cracks could be detected in any part of the masonry.

Calculations of strength are not given.

M. A. E.

The Canals, Roads, and Railways of Finland. By M. Strukel.

(Allgemeine Bauzeitung, 1889, pp. 41 *et seq.*)

The means of communication by road, rail and water, possessed by the Principality of Finland, form the subject of a series of articles, in which the Author deals in detail with the chief public works that have been undertaken in that country up to the present time. Finland comprises an area of 144,210 square miles, of which 15,863 square miles, or 11 per cent., are water, *i.e.*, lakes and rivers, and 28,842 square miles, or 20 per cent., morasses and swampy ground now in course of drainage. The land is gradually rising, the alteration on the coast of the Gulf of Bothnia being at the rate of 3 feet per century, and on the Gulf of Finland about 2 feet. The population, which in 1886 numbered 2,232,378, live principally on or near the coast. Agriculture is their chief occupation, and the produce of the forests furnishes fully one-half of the total exports. The peasantry own about 54 per cent. of the cultivated land, the State has 38 per cent., and the remaining 8 per cent. belongs to the church, the nobility, and private owners. The forests cover 82,176 square miles, or 64 per cent. of the total surface of the land, and of this area 50,496 square miles, or 61 per cent. of the forests, are State property. Coal having to be im-

ported, wood, which is so readily obtainable, is universally used for fuel, and was till quite recently used in Helsingfors even for gas-making. The conformation of the land presents a series of terraces rising from south to north, with practically unlimited water-power, so that the land is well adapted to manufacturing industries.

The water communications form the chief feature in the transport arrangements of the country, five systems or chains of lakes and rivers traversing it in a general north and south direction. These waterways are generally frozen over for some months every year, but are free from about the middle of May to the middle of November, while the coasts are free at the end of April. The harbour of Hangö on the Baltic, at the south-western corner of the coast, is seldom frozen up, except in severe winters, so that a fairly regular steamship service is maintained with certain ports of Sweden and Germany. Of the inland lines of water communication, the most easterly, or Saima system, is the most important, extending from near Kajana to Willmanstrand, a direct distance of about 220 miles. The system derives its appellation from Lake Saima, between Nyslott and Willmanstrand, from which latter town the Saima Canal communicates with the seaport of Viborg. There is a regular steam service between the towns of Idensalmi, Kuopio, Nyslott, Joensuu, and Willmanstrand, and from Joensuu northwards through the canalized Pielis-Elf to Lake Pielis. The system does not consist entirely of natural watercourses, but comprises twelve separate canals, while the Pielis-Elf navigation includes ten canals.

The Saima Canal, one of the greatest works of northern Europe, is the outcome of projects dating from two hundred years back, when the works were first begun and abandoned. The canal, as constructed, runs through the valley of the Soskuanjoki, the total length of waterway, including the string of lakes through which it passes (viz., Nujamaajärvi, Pällijärvi, Lietjärvi, Rättijärvi, Särkijärvi, Parvilainen, and Juustelaujärvi), being 36·7 miles, of which about 20 miles is the canal itself. The total fall in this length is 249 feet, for which there are fifteen locks. The ordinary width of the bed of the canal is 40 feet and depth 9 feet, with a towpath 10 feet wide; in harder soil the width of bed is reduced to 30 feet, and in hard rock to 25 feet, the towpath being 8 feet above water-level and 5 feet wide. The largest barges on the canal are 105 feet in length, 24 feet beam, and 8 feet 6 inches draught, the effective load capacity being 260 tons. Of the fifteen locks seven are single fall, three double, and five treble, equal together to twenty-eight falls, averaging 8·9 feet each. The locks are mostly 140 feet long; the side walls have a curved vertical section, and are 6 feet thick at the top and 8 feet at the bottom, and are also curved on the horizontal plan, the clear width of the lock at each end being 25 feet and in the centre 30 feet. On account of the disintegrating action of the frost, the lock walls are not backed up, but stand

independently of the ground behind on each side, the intermediate trench being known as the "frost ditch." In winter, also, the locks are covered over and a slight current of water maintained. On the Saima Canal the drawbridges run back on rollers by hand-gearing; on the Pielis-Elf swing-bridges are used. The total cost of the Saima Canal was £500,000.

With regard to the roads, although they are good in a few places, they are generally bad, and constructed on no system whatever. The landowners make and keep the roads through their own property just as they like, so that they are frequently impassable. Village roads are made about 12 feet in width, and public roads from 16 to 24 feet, widening somewhat near the larger towns.

The railways, of which there are 1,122 miles open, are all, with the exception of the short Borgå-Kervo line, State property. The chief lines, noted in the order of their construction, are:—

1. Helsingfors, Tavastehus, and St. Petersburg line. The section from Helsingfors to Tavastehus was the first constructed, the line to St. Petersburg branching off at Riihimäki.

2. Hangö and Hyvinge line, from the port of Hangö, previously referred to, to a junction with the Helsingfors and Tavastehus line at Hyvinge.

3. Borgå and Kervo line (private company), junction with the Helsingfors and Tavastehus line at Kervo.

4. Abo, Tavastehus and Tammerfors line, connecting the first-mentioned line with Abo, the former capital and chief port of the south-west coast, and with Tammerfors, the chief manufacturing town in the country.

5. The Wasa line, from Tammerfors to Wasa, on the Gulf of Bothnia, the chief harbour of the west coast.

6. The Uleaborg line, commencing by a junction with the Wasa line, and running along the north-east shore of the Gulf of Bothnia.

7. The Savolaks line, in the centre of the country, from Kouvola, on the Riihimäki and St. Petersburg line, to Kuopio.

The chief extensions now in hand are, in the eastern part of the country, from Viborg *viâ* Sordavala (on the Lake of Ladoga) to Joensuu, and in the central district from the termination of the Savolaks line to the Uleaborg railway. Several other lines are projected.

The construction of these lines is provided for partly by the net earnings of the existing State lines and partly by a "Communications Fund," which forms an annual item in the Budget. The land in general is easy for constructive purposes, the average gradients being 1 in 100, and the maximum 1 in 80. The rails are laid to 5-feet gauge. The bridges are numerous, on account of the watercourses, but there are few other works.

The subjoined Table shows the working results per kilometre of the above lines up to 1885, the latest date to which the Author has collated the statistics.

Line.	—	1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	Earnings in 1886.
		£.	£.	£.	£.	£.	£.	£.	£.	£.	£.	Percentage on original Capital.
Helsingfors, Tavastehus, and St. Petersburg	Receipts . .	506	454	421	418	458	481	516	490	488	524	6·6
	Expenditure	318	307	324	283	273	279	290	303	292	285	
	Net . . .	188	147	97	135	185	202	226	187	196	239	
Hangö and Hyvinge . .	Receipts . .	95	84	79	75	100	82	105	96	91	97	Deficit.
	Expenditure	118	134	118	108	106	115	116	130	111	104	
	Deficit . .	23	50	39	33	6	33	11	34	20	7	
Abo, Tavastehus, and Tammerfors . . .	Receipts . .	..	203	198	164	206	232	268	256	225	233	2·7
	Expenditure	..	176	131	118	120	144	165	140	126	128	
	Net . . .	..	27	67	46	86	88	103	116	99	105	
Wasa . . .	Receipts . .	..	..	..	..	..	..	..	..	70	84	1·1
	Expenditure	..	..	..	..	..	..	..	..	63	61	
	Net . . .	..	..	..	..	..	..	..	..	7	23	
Total, net .	..	105	124	125	148	265	257	318	269	282	360	

The Hangö and Hyvinge line has from the first incurred a deficit, but this is now diminishing, and it is hoped that the position will soon be further improved. During the first two years following the opening of the Uleaborg line, the figures were rather less satisfactory, the working of the line showing (per kilometre):—

—	1886.	1887.
	£.	£.
Receipts . . .	265	220
Expenditure . .	168	141
Net	97	79

P. W. B.

Historical Considerations on the North Sea Canal of Amsterdam and its Capacity for Navigation by Ships of large Dimensions.

By A. Huet.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1888–89, p. 100.)

When the North Sea Canal was opened for navigation in 1876 it was considered to afford every reasonable accommodation for the largest vessels trading to the Port of Amsterdam. But latterly the dimensions of the locks at the entrance near Ymuiden have proved to be insufficient, and now new locks are to be built to allow ships of greater tonnage to enter the canal. These facts lead naturally to the question whether it would not be advisable from an economic point of view to omit the building of these projected new locks, but to alter the locked canal into an open navigation channel, which would offer greater facilities and occasion less loss of time where a heavy traffic of large vessels is contemplated.

The history of the long series of projects for a canal to the North Sea, brought on during the last two centuries and a half, shows that the dimensions considered necessary were increased at every successive proposal, and that in the latter designs locks were omitted altogether.

The two oldest projects known for a canal through the narrow strip of land uniting the two parts of the province of Holland are by Jan Pieterszoon Dou, and date from 1629 and 1634. These were principally designed for the supply of fresh water from the Spaarne River across the Y to the polders in North Holland in summer, and for the better drainage of these lands in wet seasons, while the accommodation of shipping formed only a

secondary consideration. The idea took no practical form during two centuries, though mooted from time to time. At last, in 1823, D. Mentz revived Dou's plans of 1634 with such deviations only as were unavoidable through the reclaiming of the Haarlem Lake. The principal feature of this proposal was the construction of a dam at the entrance to the Y from the Zuiderzee to obtain a closed fresh-water basin so as to replace the storage capacity diminished by the drained surface of the Haarlem Lake. The opening of the large navigation canal through North Holland in 1825 caused the shipping interest to lose all concern in these plans, and they were thus wholly relegated to water-supply and drainage. In a project by Kloppenburg and Faddegon, published in 1848, and in that by Van Diggelen, of 1849, trade interests were again more considered. Both followed principally the lines laid down originally by Dou, with schemes in connection for the drainage of a large part of the Zuiderzee.

In 1852 the City Engineer of Amsterdam, W. A. Froger, took the subject in hand, and it was principally due to the indefatigable exertions of this able engineer that the old idea of giving Amsterdam a direct communication with the North Sea obtained a more concrete form. His plans, however, were not accepted, but a number of different solutions were proposed, amongst others, those by a Government Commission appointed to investigate the subject. In the report of this Commission an inclination is shown to follow the principles of the Suez Canal, and the new waterway to Rotterdam, both open channels without locks or impediments to the free entrance of ships. It is remarkable that these considerations were again lost sight of in later schemes, and at the present moment regret may be felt at this change of feeling, as in some quarters doubt is expressed whether the dimensions of the new locks about to be built are not already insufficient for admitting the largest ships that may be expected to visit the port. The plans submitted by A. Caland and Lankelma proposing lockless fairways appear, in the light of subsequent experience, preferable to the works actually constructed.

The writer considers the time opportune to reopen the question now that enlargements are contemplated, which will demand heavy outlay, and wishes to remark that the plural of ship is not ships, but fleet, and that a fleet requires open channels for its untrammelled movements. The increasing trade of Amsterdam reasonably demands a communication with the ocean equal in capacity to those of Rotterdam or Antwerp.

A great number of drawings accompany the Paper.

H. S.

Progress of the Works of the Baltic Ship-Canal.

By F. Woas.

(Deutsche Bauzeitung, 1889, p. 440.)

These notes are unofficial and the result of personal observation of the works, and particulars ascertained on the ground during a visit paid by the Author.

The canal was commenced two years ago, and is the largest work of the kind hitherto undertaken in Germany; when completed it will be 61 miles long. Its course throughout is now definitely fixed, and is laid out so as to avoid the town of Rendsburg, instead of utilizing, at that point, the existing Eider Canal (running through the town) as originally contemplated. The working-drawings for the locks being still in progress, their construction will not be commenced this year; but a large quantity of building-material is already delivered at the sites. Of the many crossings of the canal, only one will be a fixed structure, viz., that at Grünenthal, about 18⅗ miles from the Elbe, which will be an over-bridge carrying the railway and high road from Neumünster to Heide. The German Admiralty required an opening of not less than 121 feet 6 inches span and 138 feet headway, so as to allow of the passage of ships of war without striking their top-masts. The bridge to be constructed will have a span of 820 feet 3 inches, and to obtain the requisite headway, it will be necessary to construct an embankment of considerable height, although the canal at that point is in a cutting of 108 feet 3 inches deep (to canal bed). The various buildings intended for the offices, dwellings of the harbour-masters, lock-keepers, and others of the working staff, are well advanced; and barracks for workmen engaged in the construction have been erected at various points along the canal course. Twelve of these latter were noticed, of sizes sufficient to accommodate from one hundred to five hundred men. It was supposed originally that very considerable barrack-room would have to be provided; but it is now found that the buildings already erected are more than sufficient for the purpose, as the number of labourers requiring quarters is much less than was at first expected. This is due to the vicinity, in the eastern portion of the canal, of the towns of Kiel and Rendsburg, and on the westward section, of the villages of Hanerau, Albersdorf, Burg, and Brunsbüttel, from which supplies of labourers may be drawn; the conveyance of men and delivery of material being rendered easy from the fact that the line of canal is intersected by four lines of railway and ten highways.

The foregoing circumstances naturally tend much to facilitate, and to lessen the cost of, construction, to which may be added the conveniences afforded by the waterways of the existing Eider Canal in the eastern district, possessing locks of 26 feet 3 inches in breadth, and a depth of water of 10 feet 6 inches; and in the western portion the Burg-Kurdensee Canal, the Burger Au, and

the Holstenau. The rate of wages, however, is abnormally high—an ordinary day-labourer being unobtainable at less than 2*s.* 7*d.*, or as a rule 3*s.*; and foremen, gangers, machine-attendants, &c., command 10*s.* per day, which includes quarters.

As regards the present position of the works in general; at the Elbe end, about one-fourth of the excavation for the lock is completed, and a landing-stage and cranes are being erected by the works-executive for the delivery of stone brought from Meissen, conveyed in the Elbe barges to Hamburg, and thence by sea-going vessels.

An enumeration is given of the various places where excavation is being executed. Throughout the Elbe-level the works are light, but at 10½ miles, where the canal leaves the latter, the first heavy cutting (49 feet 3 inches to canal bed) occurs. There are here at work one mud-dredger (*Nassbagger*), and several steam-navvies (*Trockenbagger*). The contract price is 9*d.* per cubic yard. The works are untouched between 13 and 17·4 miles. At 18·6 miles the Grünenthal cutting has been begun, and the works are being prosecuted vigorously, there being seven steam-navvies at work day and night, and fourteen locomotives are employed in running out the "muck" to form the above-mentioned embankment. From this point there is a length of 24·8 miles untouched; but the works on this section will be of a very light character (say 11,000,000 cubic yards in all). At 6·2 miles beyond Rendsburg the works in progress recommence. Here the course is identical with that of the old Eider Canal, excepting where the sharp curves of the latter have been improved, and then part of the waterway passes through the Eider See, after which the Eider Canal is departed from, and for a length of 6·2 miles the course is in cutting, ranging from 33 feet to 49 feet in depth. The excavation is used for the embankment across a short stretch of moorland. Here there are two steam-navvies at work, which, owing to the nature of the soil (light dry sand), deal with 2,700 to 3,300 cubic yards per day, the contract price being 6·6*d.* per cubic yard.

The Flemhuder See is traversed for about $\frac{5}{8}$ mile, the course being the same as that of the old Eider Canal, it being, however, necessary to dredge sufficient to attain a depth of 23 feet of water, which is now being effected; the normal level of the lake is preserved by a dam on each side of the canal. From this point to the termination of the canal, at its outlet into the harbour of Kiel, the works have been commenced at several isolated places where the new canal deviates from the old, five steam-navvies being in operation, and at the site of the Holtenau Lock one of these machines is at work. Lastly, a dredger is employed in deepening the channel in the harbour.

It is expected to divert the navigation from the old to the new canal in 1893.

D. G.

Rope-Haulage Trials, Oriolle System. By P. de Monicourt.

(Le Génie Civil, vol. xvi., Nov. 2, 1889, p. 3, 5 woodcuts.)

The improvement of the inland navigation system of France has produced a rapid increase in the number of the vessels traversing the waterways, so that the tonnage has augmented 30 per cent. This increase, however, by encumbering at times the principal waterways, has raised the cost of transport, so that haulage by telodynamic cables is being tried. The earlier experiments of Mr. Oriolle, on a section of the St. Quentin Canal, which failed to keep the cable in place, indicated that the three following conditions should be realised:—(1) To place the cable on its supports, so that it is unable to leave them, whilst reducing the friction to a minimum; (2) to enable the boatman to attach his barge to, or to detach it from, the travelling cable at pleasure; (3) to furnish the barge with an apparatus for gradually increasing the traction at starting, and preventing it exceeding a given maximum in the event of the barge grounding or other accident. The grooved pulleys supporting the cable are hung from their supports, and provided with a counterpoise weight at the opposite end, so that they readily adjust themselves to any suitable plane according to the varying tension of the cable, which is thus kept in place. The tow-rope is attached to the cable by a metal fastening called a menotte, which consists of a metal socket enveloping the upper part of the cable. The socket contains three steel rings, formed in two pieces, so as readily to encircle the cable; and a two-armed lever either pushes up the central ring when pulled by the tow-rope, and thus wedges the cable between the rings and imparts its motion to the tow-rope, or releases the menotte by a pull on the other arm with the cord controlled by the boatman, which then slides on the cable. The turning of the cable, moreover, in its onward motion, does not affect the tow-rope, as the steel rings can turn in the socket. The tow-rope is wound round two bitts, with cast-iron jaws, placed on the barge. In starting, the rope, in winding, turns the bitts, and gradually presses them more and more against their conical pivots, and a ratchet arrangement prevents the maximum tension of 100 lbs. being exceeded, though this tension can be modified if desired by a modification of the tension of the spring in the apparatus. The tow-rope is attached to an unlocking lever, so that when the tension on the rope is suddenly increased by the barge running into the bank, grounding, or any other cause, the pull on the lever makes it release the bitts as soon as the tension exceeds the arranged maximum, so that the rope is slackened, whilst the cord for unloosing the menotte, remaining unaltered in length, soon exerts the necessary pull, and releases the tow-rope from its grip of the cable. The portion of the St. Quentin Canal on which these trials were made is nearly 1 mile 7 furlongs in length, and traverses three locks, two bridges, and two curves, one of them with a radius of only

5 chains. The cable is composed of six strands of seven wires each, with a sectional area of 0·285 square inch. At each end of the course, the cable crosses the canal on horizontal pulleys. The cable borders the canal on each bank outside the towing-path, and is carried on pulleys suspended from light braced standards placed about 200 feet apart, the sag of the cables midway between the supports being about $2\frac{1}{4}$ feet. Where the canal is widened out at approaches to locks, causing a deflection of the towing-path, a long horizontal arm extends from the top of the standard for carrying the pulley, so as to obviate a needless bend of the cable. The cable makes a sharp dip under the bridges, situated generally at the lower end of the locks, and is guided by pulleys placed against the abutments. The cable is guided round the curves by horizontal rollers placed near the ordinary pulleys. An engine of 30 HP. works a drum which draws along the cable; and special arrangements are provided for regulating the tension, and adjusting the length of the cable. The trials were carried on daily throughout last July with satisfactory results.[1] Some estimates made by Mr. Maurice Lévy relative to a somewhat different system of rope haulage, established by him near Paris, indicate an economy of 58 per cent. with cable traction.

L. V. H.

Barrack-Arrangements on the Works for the Baltic Canal.

By — Lütjohann.

(Deutsche Vierteljahrsschrift für öffentliche Gesundheitspflege, 1889, p. 577.)

The arrangements made for the workpeople on the various large contracts now in course of execution in Northern Germany are briefly described by the Author. It would appear that, except under special circumstances, the unmarried labourers and navvies are compelled to reside in the barrack-huts erected for them on the works. These buildings have been carried out in accordance with prescribed regulations, among which stipulations are made for the provision of healthy dormitories, kitchens, and the necessary offices; a large room for meals and for Divine service; space for officials and for the post-office, and a special establishment for the charge of the sick. The latrines are to be placed so as to be immediately accessible to the living-rooms and dormitories, but must not be in contact with them; they must further be supplied with water. Each barrack was to be arranged in connection with a canteen, the purveyor being bound also to undertake the washing.

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[1] The Abstractor was present at one of the trials near Tergnier, on the occasion of the visit of the International Congress of the Utilization of River Waters, and can bear testimony to the ease with which a barge was attached to and released from the travelling cable, and the general satisfactory working of the system.

No barrack was to be situated at a distance of more than 3·5 kilometres from the men's work. In the first instance, it was not possible to make any estimate of the number of buildings needed on a contract involving 70 millions of cubic metres of earthworks, and thus at first only eleven sites have been chosen, with accommodation for one thousand nine hundred and fifty workpeople, the sizes of the barracks varying from three hundred to fifty beds.

By reference to drawings, the Author describes in detail certain of these structures. The minimum cube contents per bed was fixed by the Government Sanitary Department at 12 cubic metres. The buildings are all constructed with timber, boarded inside and out. The apartments are in all cases warmed and ventilated. The cost of each barracks-dormitory for one hundred workpeople is approximately 14,000 marks (£700); living-rooms, dining-hall, and premises for staff, 20,000 marks (£1,000); canteen, 1,800 marks (£90); latrine, 1,000 marks (£50); door-keeper's hut, 300 marks (£15), and dust-hole, 250 marks (£12 10*s.*).

The two hospitals, each with twenty beds, and their arrangement, are also described by reference to plans; they consist of three large wards, each with six beds, and a smaller one with two beds; the space per bed being 30 cubic metres.

G. R. R.

Hydraulic and Physical Effects of the Canalization of Rivers.

By B. Santini.

(Giornale del Genio Civile, 1889, p. 269.)

The most notable hydraulic and physical effects arising from the canalization of rivers and improvement of waterways occur when by diminishing the width of the channel the depth of water is increased, by either deepening the bed or raising the surface-level of the water. If the bed is not changed in any way the alteration of the water-level is permanent, but if either by dredging or by the erosive action of the water itself the bed is deepened, the raised water-level is only temporary, and gradually disappears, leaving the surface little, if at all, above its natural point, and, indeed, in cases of considerable and continued erosion, distinctly lowering the water-level. The Author, therefore, considers the subject under three heads:—(1) Channels with unchanging beds, *i.e.*, on a hard stratum unaffected by scour; (2) channels where the soil is acted on to a moderate extent by the current until the increasing depth of the restricted section restores the original velocity and consequent stability of physical conditions; and (3) channels in very loose or soft soil, where the work of erosion goes on continually to an extent which it is practically impossible to estimate or to regulate. With each of these cases he analyses as

far as possible the conditions affecting the flow of water, giving formulas for estimating the depth of water, extent of erosion, variation of level, and velocity of current. As affecting the navigable conditions of any waterway, especially with regard to up-stream traffic, it is to be noted that the advantage derived from the increase of depth of the channel may be more than counterbalanced by the increase of velocity of the current. It may also be taken as a general maxim of practical hydraulics that although canalization in the form of channels of restricted width may beneficially affect navigation, it is not calculated to improve the physical features of any river course; in fact, that the variable water-level is rarely of advantage and often distinctly injurious. Even for the benefit of navigation, it is well to limit works of canalization to channels capable of easy erosion, otherwise the advantages and disadvantages are so closely balanced that it is often difficult to say which will predominate.

The Author then proceeds to apply his formulas and deductions to an examination of a project for the canalization of the Tiber for a length of a little over 19 miles, from Alberobello to near Porte Galera. The engineer of the works estimates that the scouring of the current will deepen the bed to the extent of 17 feet, entailing a corresponding decrease of 10·36 feet in the surface of the water, while the Author considers that the erosion of the river-bed will not exceed an average of 3·75 feet, and that no appreciable difference of the water-level is to be anticipated. He concludes, therefore, that while no hydraulic advantage is to be expected, there will be an appreciable improvement for purposes of navigation, as the depth is considerably increased without any increase of velocity.

P. W. B.

The Improvement-Works on the Brenta and Bacchiglione.

By F. Cesareni.

(Giornale del Genio Civile, 1889, p. 313.)

Previously to the year 1840, the Brenta, which brings down a great quantity of alluvial deposit, discharged its waters into the Adriatic, about 2 miles north of the estuary of the Adige; but in the year mentioned its course was shortened by a lateral cut into the southern end of the Lagoon of Chioggia, its abandoned bed being utilized for a neighbouring stream, the Bacchiglione, the former bed of the latter, in its turn, being now known as the Canal Morto, and serving to collect part of the drainage of the flat tract of land to the southward. On account, however, of the silting up of the lagoon at the outlet of the Brenta threatening the harbour of Chioggia itself, and also on account of the liability to frequent floods where the waters could not be cleared off by the tortuous, shallow, and weedy channel which had gradually formed—conditions alike urgently affecting health, navigation, and surface-

drainage—it had been found imperatively necessary to cut off the Brenta once more from all communication with the Lagoon of Chioggia, and to take it direct to the sea, near to its old outlet. It was not practicable to re-connect it with the channel now used by the Bacchiglione, at the old point of transfer, primarily because the latter, a more sluggish and level stream, flows here at a slightly lower level than the Brenta; and as the greatest difficulty is already experienced in securing efficient drainage for the district, the surface of the ground being but slightly above the sea-level, and about 68 square miles of the country being entirely dependent on incessant pumping for any drainage whatever, it was impossible either to raise the level of the stream on which this drainage is dependent, or to subject the land to the additional risks of floods from the Brenta. It was therefore necessary to keep the two rivers separate, side by side, to a point about 3½ miles from the sea, where they could be united safely in one common channel.

The works on the Brenta commence at Santa Margherita di Calcinara, about 10 miles from the sea. Above this point, for some distance, the sectional area of the waterway averages 4,024 square feet, and the width of the river 240 feet. At Santa Margherita the width of the new channel has been commenced at 260 feet, the old bed being followed for nearly 2 miles to Conche, where it approaches the Bacchiglione. From this point a new cut has been made to Le Tresse, 2 miles 7 furlongs in length; whence, to Ca' Pasqua, a distance of 2 miles, where the width of the cut is increased to 330 feet, the former bed of the river has again been utilized. For this length, and mostly parallel with the preceding, a new cut has been made for the Bacchiglione. Below the confluence of the two rivers the width is increased to 490 feet; at the confluence with the Gorzone, a stream flowing in from the south, 1¼ mile further on, the width is 590 feet; and passing Fort Brondolo, by a new straight cut through the sandhills, a length of about 2¼ miles, the outlet into the Adriatic is 660 feet in width. The course of the Bacchiglione, between Palate and Ca' Grassi, has not been enlarged, the channel—which formerly belonged, as noted, to the Brenta—being of ample dimensions; but the dykes have been strengthened and improved on the whole length. After the details for the works on the Brenta had all been settled, there occurred the heaviest flood ever known in the district, in consequence of which the whole design was revised; and it is considered that, with the present dimensions and with the straight outlet to the sea, in the place of the old deteriorated channel, there will be no difficulty whatever in dealing with any emergency of flood-waters. At Santa Margherita the dykes are 2 feet 6 inches above the highest flood-level; at Le Tresse, 2 feet; and at Brondolo 1 foot. The regulation top-width of the dykes equals their height; but in bad ground this is considerably increased, and in some places is used as a roadway. In cutting through the sandhills between Brondolo and the sea, the excavation to the full section was carried down to within 10 feet of the bottom, to which latter

a gulley 105 feet in width was cut, the remainder being left to the erosive action of the water itself.

The total amount of excavation for the river beds was 5,655,000 cubic yards, of which 2,314,000 cubic yards were used in forming new dykes and strengthening old ones, the remaining quantity being taken by barges or trucks to a distance from the works.

At Conche, a siphon under the Brenta enables the drainage of the district of Sesta Presa to be still discharged into the lagoon. There are three bridges over the united channels of the Brenta and Bacchiglione; the first, at the point of confluence at Ca' Pasqua, having a length of 354 feet over the former river, and 197 feet over the latter; the second at the mouth of the Gorzone, with a length of 512 feet; and the third at Brondolo, 590 feet in length. These bridges are constructed of iron girders on brick piers, on a pile foundation; and each is provided with a central opening-span of 33 feet 10 inches.

One of the most important considerations in connection with the new works, and the absorption of the Bacchiglione into the new cut, was the provision for the drainage of the southern district already referred to, comprising originally the districts of Foresto, Fossa Monselesana, and Fossa Pultana; to which were added later five other districts situated between the Canal Roncajette and the Canal di Battaglia, viz., Pratriarcati, Savellon di Bagnarolo, Paludi Cattaio, Due Carrare, and Retratto Monselice; a territory about 25 miles in length, extending from the Canal dei Cuori to the foot of the Euganean Hills. This drainage converges to Le Tresse, where it passes by a siphon under the two rivers direct into the lagoon, thus reducing the length of the outlet channel by 5½ miles, and giving a corresponding advantage in the fall. The siphon at Le Tresse is one of the largest works of the kind in Italy. It is in two distinct parts, a distance of 552 feet intervening between the two rivers. The siphon under the Bacchiglione is 262 feet in length from face to face, and that under the Brenta 428 feet. Each comprises five parallel openings or tunnels, 14 feet 9 inches wide, with elliptical invert and roof. The sectional area of each opening is 135·6 square feet, giving a total water area of 678 square feet. In the horizontal length the clear height of the siphon, from invert to crown, is 10 feet 6 inches; this is increased by bell-mouthing to 15 feet 5 inches at the upper end of each slope. The invert and roof curves are all easy and flowing, so as to offer no impediment to the ready passage of the water. Under the Bacchiglione the horizontal tunnel is 154 feet 10 inches in length, and each of the inclines 53 feet 7 inches. The piers and arching are all in brickwork on a foundation of concrete, 4 feet thick under the horizontal portion, and 5 feet on the inclines; the invert being 10½ inches thick, and the arch 2 feet 1½ inch for the middle two-thirds, and 2 feet 7½ inches over the haunches. A concrete filling is carried up to 1 foot 4 inches above the crown of the arch, and covered with a ⅝-inch layer of cement. The facework is of ashlar masonry, from the quarries of Istria.

At the commencement of the outlet channel are sluice-gates, corresponding in span and water-area to the siphon. The gates, which are of wrought-iron, are intended to close the streams against the inflow of high tides in the lagoon, and close automatically with the rise of the tide, and may if necessary be fixed in the closed position. The angle of closing is 112° 38'. The gates measure 19 feet 8 inches in height, by 9 feet 10⅝ inches in width, and are hung on piers 5 feet 11 inches in thickness and 24 feet 3½ inches high, built on a foundation of concrete 4 feet 2 inches in thickness. Much trouble was experienced in the foundations from the inflow of a great quantity of water, which it was found extremely difficult to check, and which on two occasions necessitated the suspension of the works. It was found that the water came from the lagoon, filtering through a distance of some 800 feet under the intervening bed of the river. The soil (the nature of which had been carefully ascertained by preliminary borings) was sandy from the surface to a depth of 5 feet; then came a 6-feet 6-inches layer of loam, below which was a 5-feet bed of peat, reaching to about 12 feet 6 inches below the mean sea-level. Below this, for an indefinite depth, was the finest sea-sand, in which the excavations had to be carried to a depth of about 28 feet below sea-level. At a depth of about 11 feet 6 inches were found the remains of an ancient forest, the decayed mass presenting serious obstacles to the driving of piles. Owing partly to the large area to be excavated for the gates, the catchment-basin and the siphons, as compared with the area to be built upon, and also to the available time and the cost, it was decided not to adopt caissons, but to carry on the work in well-timbered excavations, depending upon sufficient pumping-appliances and rapid execution of the work.

The Author explains at some length the principles upon which the details of the structures were calculated and specific dimensions assigned, and gives a detailed schedule of the quantities and the cost of these outlet-works.

P. W. B.

Prevision of Floods. By E. Allard.

(Annales des Ponts et Chaussées, vol. xvii., 1889, p. 629, 1 plate.)

The height of a flood may be reckoned in two ways; either the height of the flood may be measured above the zero of the gauge, corresponding approximately with the summer water-level of the river, which is the absolute or total flood-rise, or its height may be taken above the level at which the river stood when the flood commenced, which is the actual rise. A prevision can be made either by obtaining a relation between the total rises, or the actual rises; and sometimes one method is preferable to the other, or sometimes the use of both methods gives a better mean result than either

method singly. The prevision of the flood-rise of a main river, like the Seine, at Paris, is obtained from the maximum rise of each of its affluents, by multiplying their mean by a coefficient; but, probably, a nearer approximation to the actual results would be obtained by taking into account the duration of the flood on each tributary, owing to the different times at which floods of the various tributaries reach any given point on the main river, or by varying the coefficient in proportion to the size of the basin of each tributary. By taking as abscissas the sums of the rises of each flood at the several places of observation on the upper river or tributaries, multiplied if necessary by predetermined coefficients, and as ordinates the height of each flood at the place for which a prediction of floods is desired, a series of points is obtained by means of which a mean curve can be drawn, which gives the height of the flood at the place in question for any observed rises at the points of observation above. This graphical method is then applied by the Author to the floods of the Yonne, at Sens; the Seine, at Bray; the Marne, at Damery; and the Seine, at Paris, as examples of the system; and the results are discussed, from which the following conclusions are drawn. (1.) A graphical method, representing each flood by a point, and giving curves of prevision, may advantageously replace numerical formulas. (2.) The total flood-rise measured on the gauges may often serve as a basis for previsions, in place of the actual rise. (3.) The seasons generally affect the prevision of floods; and it is possible to specify the resulting numerical corrections. (4.) Lastly, the daily prevision of the heights of a river, which is the ideal aimed at, can only be roughly approximated to in the existing state of the investigations on the subject, but will doubtless be rendered more accurate by further researches. Several numerical tables relating to floods, and their prediction from day to day, at places in the Seine basin, are appended to the article.

L. V. H.

Submarine Works of the Outer Harbour of La Pallice at La Rochelle. By HENRY MAMY.

(Le Génie Civil, vol. xvi., 1889, p. 1, 6 woodcuts.)

The north and south jetties of this harbour were first carried out from the shore to low-water of average spring tides. They were then connected by a dam constructed by tide-work, 984 feet long, along low-water mark; and the enclosure thus formed having been pumped dry, was excavated down to 16½ feet below the lowest tides. Beyond this, the south jetty had to be extended 1,004 feet, and the north jetty 410 feet; and rock had to be excavated under the sea in the space between the jetties, and in the approach-channel outside. Two movable caisson diving-bells, provided with compressed air, were employed for founding dry, in the open sea,

twenty-four blocks under water, each occupying a space of 191⅓ square yards, and the highest containing 1,504 cubic yards. The intervals, of 6½ to 10 feet between the blocks, were spanned by little masonry arches. Each caisson was 72 feet 2 inches long, and 32 feet 10 inches wide; its working-chamber, at the bottom, was 5 feet 11 inches high; and there was a watertight chamber of equilibrium above, 6½ feet high, on the roof of which an iron scaffolding was placed, 23 feet high, supporting a platform, 52½ feet by 13 feet. This platform communicated with the working-chamber by four vertical shafts, of which two were provided with ordinary air-locks for the passage of the workmen, and smaller side-locks for the supply of materials; whilst the other two shafts, for the removal of the excavations and the introduction of stone, were surmounted by air-locks for the materials with automatic arrangements. Some Schmid compressed-air motors, for working the winches, were placed on the air-locks, being fed by compressors from the shore. Each caisson weighed 110 tons, and carried a permanent load of 220 tons of masonry on its lower platform. The caisson was built on land, taken down an inclined plane at low-water, floated at the following high-water, and towed into position, drawing 11 feet of water when the equilibrium-chamber was full of air, and the working-chamber full of water. The caisson is adjusted to its exact position by the winches acting on its mooring cables, attached behind to the jetty, and in front to buoys; and it was then grounded, either merely by the falling of the tide, or by filling the equilibrium-chamber with water in deeper places. The caisson was weighted with 220 tons of pig-iron on the upper platform, to counterpoise the 400 tons of upward pressure produced by filling the working-chamber with compressed air. The bottom was first levelled, and then excavated down to the calcareous stratum on which the blocks were founded. As the masonry proceeded, the caisson was raised by twenty-four long jack-screws. Stormy weather often interrupted the work; and then the caisson was lowered on to four large masonry pillars, built up on the block to the roof of the working-chamber. When the block reached 5 feet above the level of the lowest tides, advantage was taken of the next high tide, rising up to 17¾ feet above the zero, to float the caisson into its next position, after having removed the load of pig-iron, readjusted the six moorings, and forced the water out of the equilibrium-chamber. This operation, which was easy in fine weather, became difficult in bad weather, so that sometimes it was delayed five or six weeks. The caisson was reached from the jetty, the erection of which followed about 164 feet behind the blocks, the intervening space being crossed by a foot-bridge, resting upon a light firm scaffolding, over which the little trucks with materials ran. The excavation of the 170,000 cubic yards, for obtaining the requisite depth in the entire harbour, was effected in the dry by constructing four additional blocks across the entrance, and filling up the space between them with masonry so as to form a second dam, and also closing up the arched intervals between the

blocks of the jetties, thus forming an enclosure of about 31,750 square yards. This enclosure was pumped dry, and the first dam removed; and the excavation was then carried out in the ordinary manner. The four supplementary blocks were founded 10 feet below zero, and a dam was raised on them up to 33 feet above zero; whilst two sluiceways, furnished with paddles, enabled the water inside to be drawn off at low-water down to $1\frac{2}{3}$ foot above zero. The arched spaces between the blocks of the jetties were closed at each side by panels, composed of frames, $1\frac{1}{3}$ to $1\frac{2}{3}$ foot high, formed of wrought-iron plates and angle-irons, and connected across by screw tie-rods. A vertical shaft had been constructed in each arch, so that, with the blocks and panels, a regular little caisson was formed, which, as soon as the panels had been lowered on to the layer of stone and clay filling the base of the spaces, was filled with compressed air, and a little wall built under the bottom of each of the panels, $1\frac{2}{3}$ foot high, and the material excavated to this depth. Two other little walls were then built under the first ones, and the next layer of material excavated, and so on by successive steps till the rock was reached. As soon as the space had been filled in up to $3\frac{1}{4}$ feet above zero, the panels were removed till the next site. The rock excavations outside, amounting to 13,100 cubic yards, were effected under water, by aid of Beaumont's rotary diamond drills; the 4·20-lbs. dynamite cartridges, inserted in the holes thus formed, were fired by electricity; and the débris were removed by a hopper dredger, and deposited out at sea.

L. V. H.

Quay-wall at the Government Harbour of Ruhrort.

By — HAUPT and — ROHNS.

(Zeitschrift für Bauwesen, 1889, p. 255.)

This work forms an extension of an older quay, constructed about the year 1870, and extends for a distance of 311 yards, following the bend of the harbour, and laid out with a curve of 985 feet radius.

The coping is at a level of + 20·50 (above Ruhrort gauge datum), the bed of the harbour being − 4·10 feet, the lowest water-level − 0·15 foot, and mean water-level + 8·20 feet. The natural ground is of strong clay, overlying compact gravel.

After considering five different modes of construction, which included three in ironwork, viz., wrought-iron screw-piles and cast-iron plates, wrought-iron piling with clinker backing, and a platform supported on cast-iron columns, it was concluded that a wall founded upon masonry wells would be more suitable and economical than either of the ironwork designs or of masonry on a continuous foundation of concrete laid within sheet piling.

The wall, as constructed, is founded upon thirty-six wells, 26 feet 3 inches apart, centre to centre.

These wells measure, externally, 13 feet 2 inches × 16 feet 5 inches (the latter being the dimension, at right angles, to the line of the wall), their bases being sunk to a level of − 8·20 feet, and the lowest portion, for convenience in sinking, being battered 1 in 10 for a height of 8·20 feet, above which the well-walls are vertical—excepting on the harbour-face, where the batter is continued up for the whole height, whereby the portion of wells above datum is reduced to 11 feet 6 inches, leaving a space of 14 feet 8 inches to be spanned by the intermediate arching of brickwork, springing at a level of + 8·20 feet. The thickness of the well-walls is 3 feet 3 inches, reduced at the base, internally, to 1 foot 3 inches, and the latter rest upon beech curbs of 3 to 4 inches thick, strengthened by angle-irons and bolted to the wells, the lowest thinner portion of which is of brickwork in cement. The masonry of the wells is of sandstone rubble set in mortar, composed of lime, trass, and sand, in equal parts. The interior of the wells was finally filled up to the level of + 3·28 feet with cement concrete, and the remainder with rubble masonry; the portions of shore between the wells were trimmed to a slope of 1½ to 1, and pitched with stone as a protection against wash. In the upper part of the slope, at the back of the arches, is driven a sheeting of old rails, through the gaps of which water can readily escape from the earthwork backing. The walling above the arching is 5 feet 4 inches thick at the base, and 2 feet 3 inches thick at the top, and is finished with a coping of basalt 10 inches thick. The wall face is protected by fender piles 26 feet 3 inches apart; there are mooring rings at every 39 feet 4 inches, and ladders at 157 feet 6 inches apart.

Particulars are given of the manner in which the new work was connected with the old, also of the methods of sinking the wells, by excavating and by dredging, and of the cost of labour. With three men excavating in a well, the average depth sunk was 1 foot 10 inches, and the cost of labour 37*s.* per diem. The cost of sinking with a vertical dredger was 26*s.* per day, the mean depth sunk by this method being 11 inches per day.

The total cost of the wall, 311 yards long, amounted to about £7,676 3*s.*, or £24 13*s.* 6*d.* per lineal yard (exclusive of the value of the old rails, which would add, say, 18*s.* 3*d.* per lineal yard), divided as follows, viz.:—

	£.	s.
Masonry and material	4,740	7
Well-sinking	1,129	0
Well-curbs	630	12
Driving old rails	68	16
Earthwork, &c., backing to wall	226	17
Providing and driving oak fender-piles	125	18
" fixing ladders and mooring-rings	45	8
Superintendence	168	18
Sundries	540	7
	£7,676	3

The amount of masonry and brickwork per lineal yard was 16¼ cubic yards.

Details of the prices of materials, &c., are given.

The works were commenced in August 1883, and completed in May 1886.

D. G.

New Timber Dry-Dock at the Brooklyn (New York) Navy Yard.

(Scientific American, Nov. 30, 1889, p. 341, 5 woodcuts.)

This dock, built by Messrs. J. E. Simpson and Co., of New York, on the principle introduced many years ago by their senior partner, is an excavated basin lined throughout with Georgia-pine timber, with sides and inner end sloping to the floor. The outer end is open, and is provided with heavy sill and abutment timbers. An iron caisson fits this opening and acts as a gate. The general dimensions are as follows:—Length over all on coping, 530 feet; length over all inside caisson, 500 feet; width on top amidship, 130 feet 4 inches; width on floor amidship, 50 feet; width on floor at entrance, 53 feet; width on top at entrance, 85 feet; depth of gate-sill below coping, 30 feet 6 inches; depth of gate-sill below high-water, 25 feet 6 inches; depth at centre, 32 feet 8 inches. The general contour of the dock conforms in some degree to the outline of a ship.

Around the perimeter of the dock-floor, which is 460 feet long by 50 feet wide, 8-inch tongued and grooved sheet-piling is driven, in the present instance, on account of quicksands, to a depth of 45 feet, though 7½ feet will suffice in good ground. The enclosed area is studded with round piles 12 inches in diameter, driven in rows, 3 feet from centre to centre transversely, and 4 feet from centre to centre longitudinally. Each longitudinal row of piles carries a 12 by 12 inch square timber. Upon these rest timbers of similar dimensions spaced 3 feet from centre to centre. On the latter is spiked or bolted 3-inch planking. Special rows of piles are driven to carry the keel-blocks. A space 10 feet wide beneath the centre of the dock contains extra closely-spaced piling for this purpose. Under the floor, and surrounding the heads of the piles, is a bed of Portland cement concrete 5 feet thick at the centre, and rising towards each side to a maximum thickness of 6 feet. Any water runs down to the central axis of the dock, owing to this slope.[1]

From each side of the floor the walls rise in steps at an angle of 39°. They are lined with 10-inch timbers of Georgia pine,

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[1] The sectional view of the dock shows the concrete as flush with the under sides of the transverse timbers in the middle of the dock, and rising at an incline to each wall, where it is flush with the upper sides, the inclines ending on each side the keel-blocks in a longitudinal drain 1 foot deep, being the space between two rows of longitudinal bearing-timbers.

11 inches in greatest height, but chamfered off at their rear and lower corner so that their vertical rear-face is only 3 inches. These run horizontally around the dock, in steps 8 inches high and 10 inches wide, and constitute the altars. These altars are bolted to side timbers that rise at the same slope of 39° from the edge of the flooring. Where the altar crosses the side timber, two bolts are driven, one through the tread of the altar vertically, and a second one through the riser of the altar diagonally, so as to enter the brace-timber normally. Four piles support each brace-timber at equidistant points of its length, and its lower end abuts on the flooring of the dock against square longitudinal timbers bolted thereto and representing the bottom altar. A mass of concrete, varying from 2 to 5 feet in thickness, rises under the altars for a height of 6 feet from the bottom of the dock; above this the backing of the altars is of puddled clay. Behind the coping, tongued and grooved sheet-piling is driven to a distance well below the floor-level, so as to completely surround the dock. This gives a total enclosed width of 182 feet 4 inches. Four rows of piling with cross caps are driven within the area between the sheet piling and the coping, and diagonal braces are carried from the centre of these caps to the centre of the cross-brace timbers that carry the altars.

The dock is closed by a floating caisson. This is an iron vessel with sloping stern-pieces, exactly fitting the dock-entrance. Heavy rubber packing is carried around the entrance-sills and abutments, against which the caisson bears. No grooves are used, the working of the dock being thus greatly facilitated. Two sills are provided, an outer and an inner one. This is to enable the inner or main sill, which is generally used, to be repaired. The caisson can close the dock from either sill.

The machinery for emptying the dock consists of two centrifugal pumps, 42 inches in diameter, driven by two vertical engines having cylinders 28 inches in diameter, with a stroke-length of 24 inches. The pumps have a capacity of 80,000 gallons a minute, and can empty the dock in ninety minutes when no vessel is in it. The caisson is raised or lowered by pumping out or admitting water-ballast, a small engine, boiler, and rotary-pump being contained within it. The same engine works a capstan on the deck of the caisson.

The dock, which was begun on the 16th of December, 1867, is expected to be finished by the 1st of February, 1890.

F. G. D.

Measures adopted for the Safety and Service of Reservoir-Dams.

By Dr. P. Kresnik.

(Wochenschrift des Österreichischen Ingenieur- und Architekten-Vereines, 1889, p. 313.)

This Paper refers mainly to the numerous examples of dams constructed across valleys in France (including Algeria) and Spain.

The object of such dams is to provide for an increased demand for water by the formation of storage-reservoirs which may serve any or all of the following purposes, viz., irrigation of the land, water-supply of districts or towns, driving water-wheels or other motors, feeding navigable canals; and it is stated that where the local conditions are such that a dam of moderate height (up to 66 feet) would suffice, there would be little difficulty in providing for its safety; but the case is otherwise where dams 200 feet high have to be built; here the greatest care has to be taken with every constructive detail of the work, and it is the object of the Paper to point out what precautions are necessary, and to show what injury has resulted from a neglect of such precautions.

(1.) *Nature of the Foundations.*—In the case of dams of masonry (a material equally good for low as for the highest dams), it is stated that this should be so bedded in and incorporated with the foundation-soil as to form a homogeneous whole, which can only be perfectly attained if that foundation be rock, and as examples are given the Almansa and Alicante dams in Spain, built three hundred years ago. These are 68 feet and 134 feet high respectively, are founded upon rock, and stand to this day; while the Puentes dam (164 feet high), which was built about one hundred years ago on alluvial soil, was destroyed in 1802, after ten years' existence only, by a flood which never rose higher than 10 feet below the crown of the dam. When this work was reconstructed in 1881–86 the foundation was considerably widened, and carried down nearly 80 feet below the valley bottom in order to reach rock. The Grands-Cheurfas dam in Algeria is 98 feet high, and founded on limestone-rock, but on the mountain-slope into which one end of the dam was built a cleft full of sand was found, through which the water passed when the reservoir was first filled (January 1885), and this brought about a breach nearly 33 feet wide a month after, through which the water rushed and overturned the Sig dam lower down the valley. The Gros-Bois dam (France) was built on clay soil, which became moistened as the reservoir filled and produced a sliding and bulging of the lower slope, which, however, partially recovered as the reservoir was emptied; but this phenomenon was more striking in the case of the Bouzey dam (72 feet high), which bulged out about 15 inches on the lower side for a length of nearly 150 feet.

As regards the foundation of earthen dams, it should be on an earthy soil free from vegetable matter, so as to secure thorough

incorporation of the material of the dam with that of the soil beneath; but if this soil be not thoroughly impermeable it is usual to build a puddle-wall, or core, in the body of the dam, as in England, a good example of which is quoted in the Jarrow dam of the Liverpool Waterworks scheme, which is over 85 feet high. An exception to the above rule is that of the Marengo dam in Algeria—an earthen dam 101½ feet high, built on basalt rock; but the greatest possible care was taken in the construction of it to prevent percolation of water at the base of the dam, and it has stood well to this day.

A curved plan of foundation is recommended, and is adopted in the Spanish and some French dams; but in Algeria the straight plan obtains, and three dams of this type as above shown, viz., the Habra, Grands-Cheurfas, and Sig, have been breached.

(2.) *Cross-section.*—In masonry dams this varies very much, most of the old Spanish dams having an extravagant breadth, while those of France are, on the contrary, too slight, the section having been computed on the assumption that the highest water is more or less below the crown of the dam, and to this error the breach of the Habra dam (Algeria) has been attributed; for the flood of December 1881 exceeded the highest normal water-level in the reservoir by 7 feet, and stood at 2 feet above the crown. As regards earthen dams, the case is different, as the top is usually very wide and the slopes very flat; what is to be avoided is a rush of water over the crown, and the calculations for stability must be made on the assumption that in high floods the water stands at a level with the crown.

(3.) *Precautions in Construction.*—In the case of masonry dams the stones should be dressed and squared and laid in the best hydraulic cement. Sometimes, for the sake of economy, the best mortar is used only at and near the faces of the dam, and inferior mortar in the centre, as in the Sig dam in Algeria, which, as before mentioned, was breached; it is evident, therefore, that there is a limit to such economy.

In earthen dams the material should, it is stated, be a mixture of two-thirds clay and one-third sand, and should be tipped in thin layers inclined upwards, and made as compact and watertight as possible by ramming and rolling, and it is recommended to water the surface of each layer before tipping the next above it. The English method of building a core of puddled clay, it is said, has this disadvantage—that the parts of the dam in contact with the core are apt to crack unless the greatest possible care is taken. The combination or conjunction of masonry with earthen dams is to be avoided, and masonry culverts under high earthen dams are to be regarded as dangerous, and as an instance the bursting of the dam of the Sheffield reservoir is quoted.

(4.) *Limit of highest Water-level in a Reservoir.*—This should always be below the crown, especially in the case of earthen dams, and can be arranged in various ways, viz., by discharge-channels with sluice at the head, which can be made to work auto-

matically; and by free overfalls or weirs, the length of which can be determined by prescribed formulas, dependent on the area of the catchment-basin. Examples are given of the Almansa masonry dam, where the sill of the overfall is 6½ feet below the crown, and is only 39 feet wide, the corresponding catchment-area being 77 square miles. The Habra dam has a catchment-area of 91 square miles, with an overfall 49 feet wide on the right side, and another 124½ feet wide on the left side of the dam, the sill of each being about 10 feet below the crown. In rare cases only would it be necessary to make a tunnel or culvert through the mountain-side for the discharge of flood-waters; but an example is met with in the Fureno reservoir, where the sill of the tunnel is 24½ feet below the crown of the dam. Occasionally the under- or scouring-sluices are used for discharging surplus floods, and the Habra dam is quoted as an example, but this led to the destruction of the dam when the sluice shutters failed to act.

(5.) There should be telegraphic communication between the dam and the village lying below the reservoir, in case of a breach, and it is stated that, for want of such warning when the old Puentes dam was breached in 1802, six hundred and eighty inhabitants of the village of Lorca (about 7 miles down the valley) were drowned, but this defect was remedied on the reconstruction of the dam in 1885.

Arrangements for Service.—These are, first, the appliances for drawing off the water; and, secondly, those for cleansing the reservoir from the mud, sand, &c., brought down by floods. For the first purpose the Spanish system consists of a well, built just within the upper face of the dam and extending to the bottom, and communicating with the water in the reservoir by numerous small openings furnished with shutters, and is drawn off on the lower side through a culvert or pipe passing under the dam. In the French system the openings are fewer and larger, and in the Gros-Bois dam there are only two, the sill of the upper being 18 feet and that of the lower 60 feet below the crown. The culvert leading from the bottom of the well is sometimes divided by a short partition wall, in order to make the shutters more easy to work; for instance, in the Vingeanne dam (France) the two branch channels are 2 feet 7 inches wide and 3 feet 3 inches high, while the main culvert is 6 feet 3 inches wide, and a similar arrangement obtains in the Bouzey reservoir.

Scouring- or under-sluices are constructed for the second purpose above mentioned. The amount of silt deposited in reservoirs depends on the catchment-area, the rainfall, and the geological character of the soil. In the Sig, Tlelat, Djidionia, and Habra reservoirs, in Algeria, the yearly deposit is from 0·16 to 1·6 cubic yards per acre of catchment-basin. It is stated that the most simple and effectual method of cleansing the bed of a reservoir is by the sudden opening of a large under-sluice, which produces a violent rush of water which carries off the silt with it; but this involves a great waste of water. The Alicante reservoir was

cleansed in this way after an accumulation of ten years' deposit; the cost was £400, and 2,600,000 cubic yards were removed. But reservoirs should be cleaned out annually or every three or four years, as the silt is then looser and easier to carry off.

For closing the sluice-openings, either beams working in grooves and gates or shutters are employed; the former is the system in the older Spanish dams, and also in the Habra dam in Algeria; it possesses the advantage of simplicity of action, and can be adapted to large openings, but it has this disadvantage, that once opened, the sluice can only be closed again after the reservoir has been emptied.

In the Habra dam four men are employed to open the sluices, and it takes them five hours and a half to open them completely, that is, to a height of 6½ feet, hence much water is wasted in the process; but in the Puentes dam steam-power is used. In the earthen dam of Marengo the sluice is provided with a door, which can be kept closed by a bar or rod hinged on the door at one end, and the other end secured by a pin attached to a draw-bar worked from the top. By lifting out the pin the bar is released, and the pressure of water on the door forces it open; this method, however, has the disadvantage of not being able to close the door again till the reservoir has been emptied.

In order to remedy the defects of the methods hitherto employed, Calmels and Jandin have invented special appliances. Calmels uses compressed air, which is blown on the deposit of silt through a tube and so loosens and stirs it about that it can be carried away by the rush of water through the under-sluice. Jandin uses a pipe or tube, one end of which lies in the deposit of silt, and at the other end is attached a suction-pump; this method is efficient, but costly.

A large Plate accompanies the Paper, containing cross-sections and other details of the dams referred to.

W. H. E.

Statistical Review of the Results of the Irrigation Works of India in 1887–88.[1] By R. B. B.

These works are divided, for statistics, into two main classes, namely, Major Works and Minor Works: the former are works of greater magnitude, mostly constructed by the British Government; the latter are, in many cases, modifications or improvements of the old native systems. The Major Works are subdivided into (A), works carried out with borrowed money, and (B), with money from the Indian revenues; and the Minor Works (A), of which

[1] This pamphlet, entitled "The Irrigation Works of India: a Statistical Review of the Financial and Agricultural Results obtained from them in 1887–88," Calcutta, 1889, is in the Library of the Institution.

capital and revenue accounts are kept, and (B), of which no capital accounts are kept, carried out in both cases by means of the public revenues. Tables furnish particulars about each of the four classes of works. There are thirty-four Major Works (A), which have cost 25,500,000 Rx. (ten rupees), or about Rx. 28, on the average, per acre which may be irrigated, varying from the Ganges Canal, which cost only Rx. 19·5 per acre, to the Orissa system, costing Rx. 56·9 per acre, omitting the Cauvery system, which, from peculiar natural causes, is the cheapest of all; and 90 per cent. of the sanctioned works of this class have been completed. All these works were expected to give a revenue in excess of the interest on the borrowed capital; but hitherto only ten of the works have yielded a profit exceeding 4 per cent., and none of the works in Bengal and Bombay have paid. On the whole, however, the gain to the Government has been nearly 3,000,000 Rx., which is almost entirely due to the very large returns from the Eastern Jumna, the Western Jumna, the Godaveri, and the Cauvery Canals, amounting to a surplus revenue of nearly 8,000,000 Rx. Nevertheless, the total net return in 1887–88 was only 3·28 per cent., owing partly to the undeveloped state of the new works, but mainly to the unremunerative works undertaken by the Government within the last twenty years. The fourteen works constructed previous to 1869, but subsequently extended, paid nearly 8½ per cent. on their capital cost in 1887–88. The eleven works, opened in 1869–78, chiefly in Bengal and Bombay, taken together, did not cover their working expenses in 1887–88, and are for the most part unlikely to be ever successful financially; and the eight works opened in 1879–88 were worked at a small profit in 1887–88, but, with the exception of the Kurnool Canal, will probably pay in the end. Out of the six provinces over which these works extend, Madras and Sind are prominent from the thorough success of all the works which have been in operation over ten years. The six Major Works (B), known as Protective Works, of which the earliest was opened in 1884, are designed to irrigate 610,466 acres, at an average capital cost of Rx. 29·2 an acre. Though only recently opened, and not expected to be remunerative, two out of the five nearly completed works, namely, the Swat River Canal in the Punjab and the Gokak Canal in Bombay, rather more than covered their working expenses in 1887–88; and the first may be ultimately remunerative. Of the fifty-four Minor Works (A), comprising perennial, inundation, and navigation canals, reservoirs, tanks, embankments, &c., about one-fourth were originated by the previous native rulers, and have been improved by the British Government. They return 4·16 per cent. on the capital outlay; but this higher percentage, than in the case of the intended productive Major Works (A), is partly due to the omission from the capital account of any estimate of the value of the old works when taken over, and result mainly from the large returns of the Irrawaddy embankments in Burma, the inundation canals of Sind, and the Calcutta and Eastern Canals in Bengal. The numerous Minor

Works (B), though of small importance in themselves, are very valuable to the country, both financially and for agriculture; and their net receipts amount to over 900,000 Rx. The gross area irrigated in 1887-88 by all the works was over 12,000,000 acres, or nearly 20,000 square miles, an increase of nearly 7 per cent. on the preceding year. The water-rate for irrigation varies from Rx. 1 per acre for rice crops in parts of Bengal and Sind, up to Rx. 20 per acre for sugar-cane crops in Bombay; the average rate is rather under Rx. 3. The chief crops irrigated are sugar-cane, wheat, rice, cotton, and indigo. The average value of an acre of irrigated crop is Rx. 27; the value of the crops raised exceeds 30,000,000 Rx., and one-half of this sum is due to the increase of the crops by irrigation. In Sind and part of the Punjab, with an annual average rainfall of 3 or 4 inches, the crops depend on irrigation; whilst in Bengal, with a large average rainfall, and also in Bombay, crops can generally be raised without irrigation; but even here, in years of drought, the crops would perish without irrigation. The capital expended by the government on irrigation works amounts to 31½ million Rx., affording a net return of about 3¼ per cent., and, with the revenue derived from the Minor Works (B), the irrigation works yield a total net return of nearly 2,000,000 Rx. a year. The irrigation works, moreover, both largely increase the total products raised, and also afford a valuable security against famine.

L. V. H.

Steamers for Goods-Traffic on the Rhine. By J. Schnell.

(Zeitschrift für Bauwesen, Berlin, 1889, p. 401.)

The Rhine goods-traffic is mainly carried on by the three following methods, viz., by tug-boats (*Seildampfer*), with special gearing for hauling on a chain or rope laid on the river-bed, and having in tow barges, &c.; by freight-steamers (*Frachtdampfer*); and by vessels in tow of ordinary tug-boats (*Schleppdampfer*).

Of these methods, the first mentioned is that in general use for the heaviest traffic, comprising the conveyance of coal from Ruhrort and Duisburg to the Upper Rhine, in lighters constructed of iron or steel, or timber-built barges; whilst the rope-geared vessels and goods-carrying steamers, under ordinary circumstances, only convey a comparatively small amount; the Author therefore treats principally of the construction of the most modern tow-boats, and of the freight-vessels (barges, &c.).

The rope method was first adopted on the Rhine between Emmerich and Bingen about the year 1870, but it was soon found that the current, acting on the fine sandy bed of the river, affected the wire-rope and the wheel-gearing of the tow-boats to such an extent as to make the cost of working very considerable, and that it could only be used with advantage on the

section between Bonn and Bingen, where the circumstances were more favourable, and this length was worked profitably with eight tow-boats in the manner described, viz., by picking up the rope, which passed around side wheel-gearing actuated by high-pressure engines. For progressing in the ordinary manner, these vessels were also fitted with twin engines, actuating screws of 3 feet 3 inches and 4 feet diameter. As an instance of this type, a description is given of tow-boat No. VI; the length of which is 150 feet; the beam 24 feet 8 inches, having a draught, with 30 tons of coal on board, of 4 feet 1 inch and 4 feet 7 inches, fore and aft respectively. This vessel is capable, with a development of 180 HP., of towing 2,000 tons in four iron barges, at a speed of 3 miles per hour, the consumption of coal per hour being 595 lbs. (270 kilograms). The crew consists of ten men.

A Table is given comprising the details of cost of working, &c., of an ordinary tug-boat and a submerged cable-vessel, which, principally on account of the cost of laying and maintenance of the rope, is in favour of the former.

The freight-steamer, "Industrie I," plying between London and Cologne, built at Kynderdyk, near Rotterdam, has a length of 200 feet, breadth 28 feet 6 inches, and depth 19 feet. The draught on the river is 8 feet 3 inches, with a lading of 500 tons. Her sea-draught, with the same lading and 250 tons of water ballast, is increased to 11 feet 4 inches.

The engines are of the compound type, working at a pressure of 80 lbs., indicating 432 HP. when making 124 revolutions per minute, and actuating twin screws of 7 feet 3 inches diameter. Her speed at sea is 10 knots per hour, and on the Rhine, against stream, 9 knots per hour. The crew comprises thirteen men. Two other vessels have since been built on similar lines.

Besides the foregoing freight-vessels, there are others used exclusively on the Rhine, principally between Rotterdam and Mannheim, which carry goods, and also, at the same time, take vessels in tow. The newest and largest of these are paddle-steamers. An example is given of the "Gienanth," built in 1885. Her length is 243 feet; beam, 26 feet 3 inches; breadth over paddle-boxes, 50 feet. The draught, with 10 tons of coal and 20 tons[1] of cargo, is 4 feet 6 inches. The engines are of the compound type, working at a boiler-pressure of 100 lbs., with an indicated HP. of 600 to 650. The average speed against stream (without anything in tow), with a lading of 200 tons, is 7½ to 8 miles per hour; and with the same lading and 900 tons in tow, in two iron barges, is 3·1 miles per hour.

The tug-boats in use are either paddle- or screw-steamers, the former being more general, owing to the occasional shallowness of the channel; otherwise, could a minimum of from 8 feet to 10 feet depth be depended upon, the screw-propelled boats would be almost entirely adopted, as they can be worked at 20 per cent.

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[1] *Sic* in original; probably 200 tons is meant.

less cost than the former; the screw-boats, however, can only, as a rule, be used as far as St. Goar or Oberwesel.

Screw-boats were first introduced on the Rhine in 1880; the diameter of the screws being then from 5 feet 3 inches to 6 feet, actuated by engines of 300 to 400 HP., the length and breadth of the boats being from 98 feet 6 inches to 118 feet, and 16 feet 5 inches to 19 feet 8 inches respectively, with a draught of from 6 feet to 6 feet 7 inches.

A detailed description is given of one of the largest screw tug-boats in use on the lower Rhine; viz., the "Franz Haniel III," built in 1884. She is constructed of Siemens-Martin steel, and has a length, breadth, and depth of 141 feet, 24 feet 7 inches, and 10 feet 7 inches respectively; her draught when in full working order, with 80 tons of coal on board, is 8 feet 3 inches. The engines are compound; the twin screws 7 feet 3 inches diameter, and she is capable of towing four iron barges (*Kähnen*) from Ruhrort to Cologne (56½ miles), in from nineteen to twenty hours. The coal-consumption is 1,764 lbs. per hour, and the I. HP. 850 to 900. A description is also given of the paddle-steamers, and the earlier are compared with the most modern types. The latter are fitted with triple-expansion engines, effecting a saving of 25 per cent. over the earlier compound engines.

By the end of the present year there will be three of the latest type in service.

Full particulars and drawings are given of one of these, viz., the "Franz Haniel VI," built under the superintendence of the Author, the main ends striven to be attained being the greatest towing-power combined with the least possible draught, and least consumption of coal. The length of this vessel, which is constructed of Siemens-Martin steel, is 249 feet 4 inches; beam 29 feet 10 inches; breadth over paddle-boxes, 55 feet 9 inches; depth, 11 feet.

The specified draught, when in full working order, with 10 tons of coal on board, was 3 feet 3 inches; the I. HP. 1,000, and the consumption of coal 1·43 to 1·54 lb. per HP. per hour, these conditions being fulfilled when brought into actual service in November 1888, when from 3,500 to 4,000 tons, laden in four iron barges, was towed from Ruhrort to Cologne in from twenty to twenty-two hours.

Drawings, and a full description, are also given of the most recently constructed barges (*Schleppkähne*), which are now built for a lading of 1,200 to 1,300 tons. They are constructed of Siemens-Martin steel; are 239 feet 6 inches long, 32 feet 10 inches beam, and have a draught of 7 feet 10 inches, when laden with 2,500 tons.

D. G.

On the Theory of Disinfection by means of Steam.

By Dr. H. ROHRBECK, of Berlin.

(Gesundheits-Ingenieur, 1889, p. 670.)

The various investigators whose experiments have recently been published are unanimous in declaring that disinfection by means of hot air is far from ensuring the same successful results in the destruction of the bacteria as are obtained by the use of steam. The differences of opinion turn rather upon the question of the relative efficacy of moist steam at 100° Centigrade and of dry superheated steam. Gruber has lately conducted some experiments to test the relative rapidity of penetration into the interior of the objects to be disinfected of hot air, saturated steam at 100°, and unsaturated steam at 120°, but he does not express any opinion as to the action of saturated steam at temperatures above 100° Centigrade. The Author states that all investigations point to the superior sterilizing power of moist saturated steam as compared with dry superheated steam, which latter is little better for the purpose than hot air. Esmarch has conclusively shown that only when a temperature of 150° is reached are anthrax spores destroyed by dry steam, though even 110° in the case of saturated steam was fatal to the spores, and the recent experiments of Globig confirm these results. The reasons for certain discrepancies in the observations of these authorities are discussed. The Author points out that it is possible to obtain steam at temperatures considerably above 100° Centigrade, either in a dry or in a moist state; this is only a question of pressure, which must be studied along with the other conditions, and he refers to experiments with a digestor to which a manometer was attached. In the first case steam was got up with the outlet-valve closed, and then an internal pressure of $\frac{3}{4}$ atmosphere was registered before the temperature of 90° was attained, while before 100° Centigrade was reached the internal pressure was considerably over 1 atmosphere. But if, under exactly the same conditions of heating, the experiment was repeated, and the outlet-valve was left open until steam was freely evolved, so as to drive the air out of the apparatus, and the valve was then closed, the pressure of 1 atmosphere was not recorded until the temperature of 121·7° was obtained, which corresponds with that for saturated steam at this degree of tension. If, however, the steam is dry, the behaviour is quite altered, and a manometric pressure of a little more than $\frac{1}{8}$ atmosphere was recorded when the steam-heat had risen to 119°. The Author states that he was able to superheat the steam in the apparatus of Nägeli by causing the flame to play on the side of the vessel above the water-line. For a rise of temperature of 1° Centigrade the gaseous vapour expands $\frac{1}{273}$ of the original volume, or with an initial pressure of 1 atmosphere the increased pressure of the superheated steam would only amount to 2·07 millimetres of the manometer,

while in the case of saturated steam the increased tension would be equivalent to about 27 millimetres.

From these experiments the Author deduces the conclusion that if the observed pressure is greater than that which would follow for the corresponding temperature from Regnault's law, the steam is mixed with air, and is not pure. If, again, the temperature is higher than the corresponding pressure, the steam is superheated, and only when the manometer indicates the required pressure coinciding with the observed temperature is the steam pure and saturated. It will not be surprising, therefore, if steam, which thus varies in its physical properties, varies also in its physiological action. The Author points out the practical bearing of these conclusions, and states that he is engaged in the construction of an apparatus, in which advantage is taken of the facts above indicated.

G. R. R.

On the Number of Bacteria present in the Soil.

By John Reimers, of Jena.

(Zeitschrift für Hygiene, 1889, p. 307.)

The previous investigations, which date from those undertaken by Birch-Hirschfeld at Dresden in 1874, are discussed, and reference is made to the importance of the discovery by Pasteur, in 1877, of the bacillus of malignant œdema, and in 1880 of that of anthrax in the soil. The first quantitative examination of particles of earth is due to Koch, who cultivated colonies arising from samples of soil in gelatin in 1881; but, as Fränkel has pointed out, his methods were imperfect. The plan of procedure adopted by Miquel and Adametz is also, as the Author shows, not to be depended upon. The investigations of Beumer, Maggiora, Smolenski, and Fränkel are in turn examined, and the Author lays down the following conditions for the successful solution of the question:—(1). Everything that comes in contact with the sample of the soil to be tested must be perfectly sterilized; from the moment of its withdrawal from the earth, until it is shaken into the glass tube for gelatin-cultivation, the soil must be protected to the utmost extent possible from external impurities. (2.) Only absolutely fresh samples, and such as can be at once examined, are suitable. (3.) The investigation, based upon equal parts by volume, gives more reliable results than equal parts by weight; and (4.) The specimen of earth tested must be forthwith introduced into the gelatin, in order that, as far as possible, all germs may come under cultivation.

Instead of $\frac{1}{50}$ cubic centimetre employed by Fränkel, the Author used $\frac{1}{10}$, as the tests, especially those from the deeper strata, based on a larger proportion of the soil, are obviously more trustworthy.

The prosecution of the drainage-works in Jena rendered it possible to obtain from the trenches, in course of excavation, reliable samples in all kinds of soils, at various depths, and thus to avoid the necessity of having recourse to borings, as had been the case in previous experiments. The plan adopted in making the tests was to reduce $\frac{1}{10}$ cubic centimetre of the soil, mixed with fluid gelatin in a sterilized agate mortar, to the finest possible state of subdivision. For the measurement of the sample a metal spoon was employed, which contained, after the particles of soil were perfectly levelled by means of the knife, which had been previously heated to redness, exactly $\frac{1}{10}$ cubic centimetre. The precaution used in filling the tubes and in estimating the colonies are described. The results of the various experiments on virgin soil outside the town, soil from beneath the roadways, from ground that had long been built over, from gardens, from land adjacent to factories, and from courtyards and cemeteries, are set forth in detail. In general the figures coincide more nearly with those of Fränkel than with the facts as given by other experimenters. The numbers of bacteria rapidly decrease in the deeper layers of the earth, both in the case of virgin soil, and in soil that has been polluted in various ways. The rapid decrease may be seen from the following figures:—

	Depth below Surface in Metres.	Germs per Cubic Centimetre.
Experiment 6	1	124,800
„ 6	2	750
„ 8	1	15,820
„ 8	1·60	360
„ 12	1	64,200
„ 12	2	590

In Experiment 18 the decrease was very marked, even at 1 metre in depth; for while at the surface there were 432,400 germs, there were but 760 germs per cubic centimetre at a depth of 1 metre. In the cemeteries very similar conditions were found to prevail. The Author thus sums up his general conclusions on the whole subject:—

(1.) The number of germs in the upper layers of the soil is by no means so great as many previous observers have stated. In the soil of this district (Jena), it never exceeds a few millions per cubic centimetre (7,600,000 in the worst case).

(2.) Up to a certain depth the number of germs remains relatively high, but always less than at the surface.

(3.) At increasing depths there is a tolerably sudden and marked decrease in the numbers, as Fränkel has already pointed out.

(4.) The zone of this sudden diminution lies in the Jena soil, as in that of Berlin, at a depth of between 1 and 2 metres.

(5.) The position of this zone would appear to depend chiefly upon the amount of superficial disturbance, and the mode of employment of the site in question. In made ground it lies deeper than in virgin soil.

(6.) Even at quite moderate depths (2 metres) it is possible to find soil that is germ-free.

(7.) The same kinds of germs, in strata near the surface, show more vitality when under cultivation than those obtained from the deeper layers of the sub-soil.

Five other conclusions have reference to the action of the sub-soil water; the pollution caused by interments, &c.

G. R. R.

The New Crematory at Zurich.

By A. Geiser. Stadtbaumeister.

(Schweizerische Bauzeitung, vol. xiv., 1889, p. 37.)

The disposal of the dead by cremation is not new, but of late the subject has been taken up with the view of dealing with it scientifically. On the crude method of burning the body in the open air on a funeral pile, the latest system here described, that of Mr. Emile Bourry, a French civil engineer, is a great advance. Both Venini, of Milan, and Siemens, of Dresden, have worked out systems, and have each erected a crematory. Venini, by means of the combustion of wood-gas, mixed with air, consumes the body by a flame impinging directly on it. Siemens puts the body into a furnace previously heated by gas, and admits to the furnace fresh air, which takes up the heat accumulated in the brick and ignites the body. Bourry, heating the furnace first of all by means of a coke stove, improves on Siemens' system, by using the heat developed in the combustion of the body itself to heat a cellular system, through which the feed-air is passed. Thus not only economy of fuel is obtained, but also in the time between any two cremations, as two or more may be consecutively carried out without waiting to re-heat the oven, which is necessary in Siemens' system. The preparatory heating, as also in Siemens' method, takes from eight to ten hours, the weight of coke being approximately 20 centners (about 1·94 ton), costing from 40 to 50 francs, but for a second or any following cremation only 2 or 3 centners more are required. The temperature of the furnace appears in every system to be about 700° or 800° Centigrade. Other advantages of the Bourry system are:—(*a*) The chimney from the furnace need be only 10 metres (33 feet) high, and is therefore concealed in the building; (*b*) the whole operation, from beginning to end, is carried out in full view of the relatives; even the actual combustion of the body in the furnace may be watched through a small opening. To preserve the outward semblance of burial Siemens uses a grave-like opening in the floor through which the body is lowered, and from which, unseen by the bystanders, it is moved into the furnace. Bourry, however, laying particular stress on every operation being visible, has the coffin placed on an iron table along which it is made to slide first

into an iron case, the door of which is then closed, and then, the door being opened, the body is slid into the glowing furnace. The actual time of burning occupies (for an adult) two hours without and two hours and a half with, a coffin; at the end of which time a lever is moved actuating a kind of rake, which gathers the ashes to a funnel-like opening on one side of the front of the furnace, from which they fall silently into a small earthenware urn placed to receive them. The lid of this urn is then closed, sealed, placed in a larger funereal urn and delivered to the relatives of the deceased. The whole operation is noiseless and reverent.

The Zurich crematory was commenced in the autumn of 1887 and finished in the course of the following year. The façade is of Ostermunder sandstone, the base and steps being of granite. It consists of a large hall, 41 feet long by 23 feet wide by 24½ feet high, containing the furnace, and adjoining to this two rooms, the one for waiting, the other for registration and storage of papers, each approximately 14 feet by 9 feet. The cost, exclusive of the land, which was the gift of the city, was £2,080.

The Paper is illustrated by scale drawings and photographs showing the exterior and interior of the completed building.

E. L. W. H. S.

Wery's Apparatus for heating Retort-Furnaces. By L. Brémond.

(Journal des Usines à Gaz, 1889, p. 153.)

The cost of fuel for heating retort-furnaces is a most important expense in the manufacture of gas. Various recuperative furnaces for utilizing the waste heat are known, likewise the non-conducting coverings of Le Treust and others, besides other means that have been proposed for economizing the fuel. It costs the Paris Gas Company 14½*d.* for fuel for producing 35,300 cubic feet of gas, while the cost to many other companies is double that amount, and, in small works, the cost rises to as much as 9*s.* 7*d.* per 35,300 cubic feet. These differences may be partly due to variations in the price of the fuel; the coke being, in some places, valued at the selling price, while others calculate it at a uniform and conventional rate. However this may be, considerable variations do exist in the quantity of fuel used for heating the furnaces, even in the best managed works of similar sizes, and the differences become enormous if small works are compared with large ones. It is therefore desirable to find a simple and inexpensive means for economizing fuel, applicable to all gasworks, and Wery's apparatus fulfils these conditions, effecting a saving of from 15 to 20 per cent. in the fuel.

On behalf of the Mechanical Arts Committee of the "Société d'Encouragement," Mr. Pihet has reported on Wery's smoke-consuming chimney, the principles of which are simply to mix a certain quantity of relatively cold air with the furnace gases in

the chimney; this is effected by the application of the principle of Giffard's injector; the air mixes with the hot gases in the chimney, passing through a circular orifice, reduced in section as much as possible, and proportional to the chimney. The current of cold air surrounds the furnace-gases in motion, mixes with them, lowers their temperature and diminishes the velocity of the draught. Without considering the theory of the principle, or determining whether similar results could be obtained by carefully regulating the dimensions of the exit orifice, Mr. Pihet found, from two carefully made experiments, that the Wery process was efficacious both for smoke-consumption and economy of fuel. He experimented with a 12-HP. portable engine and a tubular boiler without return flues or artificial draught. The consumption of smoke was perfect, and the economy of fuel, with Wery's apparatus, for an equal amount of work, and for the same quantity of water evaporated, amounted to 23 per cent.

Other trials were made by Mr. De Bange, General Director of the old Cail manufactory at Paris, with 20-HP. and 80-HP. engines, and with puddling-furnace and generator-furnaces: decided economy of fuel was found, and also a sensible reduction in the time required for getting up steam. With the steam-boilers, the saving was about 20 per cent., and with the puddling-furnace, in addition to the economy of fuel, the quality of the iron was superior to that obtained before using the apparatus. Mr. De Bange also made a trial to determine the quantity of water evaporated per pound of coal, with and without the apparatus, and found that the steam produced per pound of coal was increased by 28 per cent. by the apparatus.

Trials were also made at Denain by Mr. Jubeau with a puddling-furnace on two steel ingots, each weighing about 4 tons, in two similar furnaces, the one with, and the other without the apparatus; these showed an economy of fuel of 16·79 per cent. in favour of the apparatus.

Other trials have also been made by Mr. J. Gaudry in the shops of the Compagnie Transatlantique, at Penhoet, which gave 10·2 to 10·7 lbs. of water evaporated per pound of coal with the apparatus as compared with 7·8 lbs. of water per lb. of coal without it.

As regards gasworks, the Wery apparatus produces a similar effect to that of Le Treust, which creates an intermittent draught in the chimney and drives the products of combustion back into the furnace when the register is closed. With the Wery chimney, vacuum and pressure are alternately seen, according to the condition of the fuel. No machinery or steam is required. It can be fixed to existing chimneys, but the most convenient plan is to construct a brick foundation and place the apparatus on it, surrounded by a sheet-iron chimney. An apparatus and chimney of a total height of 30 feet, and the chimney 11¼ inches diameter, was substituted for a brick chimney 62 feet high and 35½ inches diameter; so that such large chimneys are not required, and the flames are not seen escaping at the top. At the small gasworks

where it is in use, and where the dampers have to be closed each evening until the following morning, the heat is maintained and the furnace regains its ordinary temperature in half the usual time; there was also an economy of 16 per cent. in the fuel in the month of March, with intermittent working; but it will be easily understood that in winter, when the furnace is working regularly day and night, the economy would be considerably greater, the more so because the apparatus gives better results when the outer temperature is low. This was proved at the same works during a twelve days' trial in November last, when the saving in fuel was 28 per cent., as compared with the corresponding period of the preceding year. The Wery apparatus is of very simple construction and requires only occasional cleaning when coal or tar are used for fuel. It is destined to become generally used in gasworks, as it will effect considerable economies which have not hitherto been realized by any other system.

C. G.

Storage of Petroleum used as an Illuminant for Prussian Lighthouses.

(Zeitschrift für Bauwesen, 1889, p. 397.)

Petroleum is almost exclusively used as the illuminant for lighthouses on the Prussian seaboard, and a description of the various special store-tanks is given, and their efficiency is considered; the principal ends kept in view being the avoidance of waste by leakage, and in drawing supplies,—and maintaining a low temperature.

The tanks are of wrought-iron, and generally of a size sufficient for storing a year's supply. Their shape is cylindrical, the larger ones of 3 feet 3 inches diameter, 5 feet 0 inch high, constructed of $\frac{5}{32}$-inch to $\frac{3}{16}$ inch plates for the sides, $\frac{1}{8}$ inch to $\frac{5}{32}$ inch for the cover, and $\frac{7}{32}$ inch to $\frac{1}{4}$ inch for the base, that which is of the main importance being an efficient closing of the joints.

They are made in four different manners, viz., 1st, of single plates with double-riveted joints; 2nd, of the same, but with caulked joints; 3rd, of the same, but with brazed joints; and 4th, with a double skin, forming a water-jacket, with single riveting and caulked or brazed joints. The third mentioned method is that found to be the most efficient, although expensive. One objection to the water-jacketed tanks is that in frosty weather the water has to be let off.

Diagrams are given showing the various forms of tanks, and of the special brickwork cellars in which they are placed, these being generally isolated from the other buildings. The tanks are fitted with glass gauges, and are filled by a hose passed through a trap in the roof of the cellar.

For comparison with the present improved method of storage, a

return is given relating to various lighthouse stations under the old system when the oil was drawn direct from the casks, and varied from 5·4 to 13·7 per cent.

A tabular statement is given of the number of tanks and their form of construction at each of the seventeen lighthouse stations, the names of the makers, the cost, cubical contents, cost per litre, and percentage of loss per annum now and formerly, the greatest loss quoted being reduced from 13·7 to 1·01 per cent.

Particulars are also given of the cost of construction of the cellars at six stations.

D. G.

The Construction of Railway Embankments in Soft Soils.

By Jhr. Martini Buys.

(Tijdschrift van het Koninklijk Instituut van Ingenieurs, 1888–89, p. 110.)

Where it is necessary to construct embankments on soils of a compressible and treacherous nature, several methods may be employed to ensure a stable foundation. In the early times of railway construction in the Netherlands, when the weights of rolling stock and loads were considerably less than at present, and the velocities of the moving loads comparatively low, the object was obtained by covering the surface of the ground with fascine mattresses, upon which the embankment was subsequently raised. In this way the existing topsoil was rendered tougher and the soft subsoil was gradually compressed and rendered more solid. With the mechanical appliances existing at that time, no other system could have been followed, and where the ground was of an exceptionally untrustworthy quality refuge had to be sought in rows of piles forming the foundation for the dams, as well as for the other works required, such as buildings, sluices, bridges, or aqueducts. These embankments, resting on the surface, have the great drawback of never settling completely and requiring constant raising, as the subsoil, under the influence of the weight of earth and the vibration of traffic, continually sinks or is pressed out sideways.

In recent years it has been practicable, through the improvements in mechanical means for transporting large quantities of material, to adopt other methods. In constructing the line Sliedrecht-Gorcum, the sections where treacherous soils had to be dealt with, the silt and the mixed strata of bog, running sand and slippery clay were removed by dredging, sometimes to considerable depths, and the trenches then filled up with sand, forming in this way a sufficiently firm and stable foundation for superstructure.

On the line now being constructed between Schiedam and Maassluis it was, however, not in every case possible to revert to this method, as the line running close to existing river embankments, and polder dams, and canals, these would have been

weakened and deflected. In these cases the top layer only of soil and turf is removed, and the sand tipped as much as possible on the centre line. The sand, of greater weight than the subsoil, sinks down, displacing the underlying strata sideways. In consequence of this the ground at the sides bulges up, and has to be levelled again, which only occasions inconvenience where canals are concerned, easily corrected by dredging. Subsequent borings show very irregular movements of soil, the sand in many cases finding its way, not always vertically down, but often sliding sideways according to the varying nature of the morass through which it sank, occasioning great differences in the time of settling. Sometimes this settling was slow and gradual, at other times intermittingly or suddenly going down at irregular intervals. The cost price of this section was about £30 per lineal yard, an amount for which a viaduct on piles could not have been constructed.

This communication is accompanied by several drawings.

H. S.

The Shafts of the Braye Tunnel.

(Notice sur les Modèles, Dessins, etc., des Ponts et Chaussées et des Mines à l'Exposition Universelle, 1889, p. 270.)

The middle section of the Brayo Tunnel is reached by two shafts known as Nos. 2 and 3, 301 feet and 378 feet deep, and distant 1,181 yards and 1,722 yards respectively from the mouth on the Aisne side, which necessitated passing through from 40 to 70 feet of the Soissons sands below the water-level. The method adopted for sinking was similar to that formerly applied in making the Rilly la Montagne tunnel in the Reims and Epernay Railway, namely, the use of cast-iron tubbing through the water-bearing bed, which was afterwards secured by under-pinning with oak cribs, the ground being kept dry during the erection of the latter by the use of compressed air.

The shafts, rectangular in section, 5 feet 3 inches broad, and divided into three compartments, of the respective lengths of 5 feet 7 inches, 5 feet and 3 feet 6 inches, were put down to about 30 feet below the water-level by the ordinary method of timber frames, 40 inches apart, and close boarded sides, when further progress by this means became impossible, and cast-iron tubbing was substituted. A separate tubbing was used for each compartment. The rings, 1·2 inch thick, and 39·4 inches high, ribbed and flanged inside, are united by bolts through the flanges, the joint being kept tight by an india-rubber ring filling seats turned into the adjacent flanges. The bottom ring was provided with a cutting edge. The erection of the tubbing-column was effected at the bottom of the shaft in a depth of 25 to 30 feet of water, and when completed pumping was

stopped, and the water allowed to rise to the natural level, in order to prevent irregular movements of the ground during the working, which, by causing dangerous hollows, were likely to endanger the timbering of the upper part of the shaft. The sand was at first excavated by a bucket-dredger, then shell augers were used, but finally divers filling the sand directly into tubs were found to be most expeditious. The diver removed the sand at the bottom of the compartment, but without uncovering the cutting edge of the tubbing; the column was then forced down by hydraulic jacks of 20 tons power, until a depth of 20 to 40 inches was attained, when the sand was again cleared out, and so on, the work being done alternately in the different compartments. It was hoped that a tight joint would have been obtained when the cutting-ring had penetrated the clay below, but, owing to the small breadth of the ribs dividing the different compartments, they gave way, and allowed the sand to penetrate from above. It therefore became necessary to have recourse to compressed air in order to render the junction of the tubbing with the ordinary timbering impermeable. For this purpose air-locks were established at the mouth of each compartment; one of these, allowing the passage of timber, was 16½ feet high, and the others 7 feet 6 inches each. The air-compressor was driven by a 15-HP. portable engine, and maintained a pressure in the bottom varying from 2·35 to 2·8 atmospheres.

The joint was formed of six oak rings, from 9½ to 10½ inches square, and from 4 feet 4 inches to 6 feet in inside diameter, built into a pile 5 feet high. The broadest rings at the bottom resting on a ledge cut in the impermeable strata, and the narrowest one bears against the bottom of the tubbing, the cutting edge of the shoe resting in a groove in the upper surface containing an india-rubber washer. The seat for these rings was made by excavating a bell-mouthed chamber, which was filled up with concrete carefully rammed after the rings had been placed in position, and packed with moss and wedged in a similar manner to that employed in coal-pit sinking. The order of placing the rings, which is somewhat peculiar, is described in full detail with illustration. The top ring, No. 1, under the tubbing, was first placed provisionally, then the broader ones, Nos. 6 to 3, were built up, and the hollow behind concreted, and finally No. 2 was driven in between No. 3 and No. 1. The joint between the tubbing and No. 1 ring was further secured by a sheet-iron ring backed by cement. Afterwards the sinking was resumed at the ordinary pressure, and secured by close cribs of oak for a depth of 6 feet, below which ordinary frames 40 inches apart are used as in the upper part.

The cost of these appliances to the two pits was £11,240 for a depth of 161 feet 9 inches, or about £210 10*s*. per yard.

H. B.

The Tunnel of Braye en Laonnois.

(Notice sur les Modèles, Dessins, &c., des Ponts et Chaussées et des Mines à l'Exposition Universelle, 1889, p. 255.)

The summit dividing the basins of the Oise and Aisne on the navigable canal in course of construction between these rivers is passed by a tunnel 2,580 yards long, at a depth of 400 feet below the crest of a ridge, which is made up of alternations of sands and clays capped by the Calcaire Grossier, the whole being of eocene tertiary age. The stratification, which is regular in the higher parts, is subjected to a disturbance at the base, so that the tunnel, which should be entirely in the lower sand, Sable de Bracheux, with about 40 feet of cover, consisting of clays and lignites between it and the overlying Soissons sands, passes through a short fold of these clays, which at 300 yards from the mouth on the side of the Oise brings the crown of the roof into contact with the upper sands, causing a great flow of sand and liquid clay into the heading, so that it became necessary to carry out this part of the work by compressed-air.

The plant required was erected in 1883; it comprised seven portable steam-engines, altogether of 220 HP., driving eight compressors capable of supplying 180,000 cubic feet of air at double the atmospheric pressure, to the working chamber in twenty-four hours. A series of reservoirs, of about 3,000 cubic feet capacity, were also provided for air at 4 to 6 atmospheres absolute pressure, which was used for the removal of the excavated material.

The working chamber at the face of the tunnel was formed by a wall of masonry, perforated by air-locks, giving admission and exit to and from the chamber. At first this wall, 11 feet thick, was placed about 400 feet from the mouth of the tunnel, but subsequently a second one, improved in many particulars, was placed at 614 feet, and the first was removed. This dam, built of concrete between retaining walls of dressed stone, was 22 feet thick in centre, and 26¼ feet at the bottom, where the two air-locks were placed; a passage for a third lock was also provided, but was walled up. In the upper part of the dam two other passages were left for the tubes serving for the removal of the débris, and these were similarly walled up when the tubes were erected.

The air-locks were of the section of ordinary mining-galleries, 26¼ feet long, 5 feet 5 inches broad, and 7 feet 3 inches high, or sufficiently large to allow the passage of mine-wagons. They were provided with a sheet-iron lining, built up in rings, bolted together with india-rubber washers, and air-tight doors closing against seats faced with india-rubber, opening inwards, *i.e.*, from the outer air to the lock, and from the latter into the working chamber. At first the doors were closed by screws, but these were inconvenient on account of the slowness in manipulation, and rack and pinion movements, governed by levers, were substituted. The pressure of the air released the lever, which was then lowered shortly

after use, so that the door was only kept close by the difference of pressure on the two sides and in the levels. They opened of themselves as soon as the two sides were in equilibrium. The outer door had only a single lever worked from within the lock, while the inner one had one on each side, so that it could be worked either from within or without the chamber. The low-pressure air was introduced by four pipes placed close to one of the walls, and that at high-pressure, for the removal of spoil and water, by a fifth near the bottom. Two 16½-inch pipes were passed through the upper arches, and two of 13¾-inch through the bottom of the wall, both series being provided with stop-valves at the ends. The larger pipes inclined outwards, and were turned up to a vertical position within the chamber. When required for use, the inside valve was opened, the tube filled with spoil and closed again. At a given signal the outer valve was opened, at the same time as that connecting the tube with the high-pressure main containing air of at least 4 atmospheres pressure, which cleared out the contents in a few seconds. The outer valve was then closed, and the filling repeated as before. In the same way the water accumulating in the bottom of the chamber was driven out by connecting the lower tubes with the high-pressure air service. The working chamber was lighted by Edison glow lamps, and a Gramme dynamo worked by a 15 HP. engine, and telephonic communication was established between the face and the office. The preparations having been completed, work was begun early in 1884, and from the first great difficulty was experienced in keeping the chamber air-tight, the compressed air finding its way out, not only through the penetrable strata above, but also along the extrados of the roof and the timber struts required for the support of the ground. It was only after building 20 inch buttress-rings on either side of the dam that the pressure on the chamber could be brought up to 1·8 and 2 atmospheres (absolute), under which condition the roof was completed to about 220 yards from the mouth, at the rate of 13 to 16 yards per month, when the work was stopped by an accident in August, 1884. This was caused by the compressed air getting into the overlying pyritic lignite-bearing strata, and after driving out the water oxidizing the pyrites, whereby sufficient heat was developed to fire the lignite, and the products of combustion penetrating to the chamber caused the death of seventeen men by suffocation. In order to render the workings accessible after this accident, six bore-holes were put down from the surface to the seat of most active combustion to give free issue for the gases, which were driven out of the chamber by projecting highly compressed air into it, the mean pressure being kept at 1·6 atmosphere. On the 4th of October the chamber was accessible, and after the ground had been properly shored up, the pressure was removed and the surface-water, being no longer kept back, penetrated to the seat of the fire and extinguished it; but the heat developed was sufficient to keep the temperature of the water trickling through the roof at 90°

for six months. After the accident the first dam was removed, and the second at 614 feet was erected as previously described. Provision was also made for the active ventilation of the part of the tunnel open to the air, by sinking a shaft a little on one side, and connecting it with the crown of the arch by a short inclined drift at 358 feet from the mouth. This shaft was closed at the top and provided with a Pelzer fan, 6 feet in diameter, with a minimum exhausting capacity of 500 cubic feet per second, a return air-way 6 feet wide being formed on the left side of the tunnel, by a brattice wall of masonry carried from the bottom of the pit to a point 13 feet behind the new dam. Working with compressed air was renewed in March, 1885, but the difficulty of keeping the chamber tight was found to be as great as before. It was therefore resolved to wall up the face at 820 feet, and increase the dam by leaving a breadth of 60 or 70 feet of ground unbroken, with the exception of three small galleries, two at the bottom and one at the crown of the arch, which were carefully lined with masonry. The upper one proved a failure on account of the large leakage at its mouth, and was blocked up by a 39-inch wall, after a length of 85 feet had been driven; but the lower ones being driven in compact clay, succeeded better, and remained perfectly tight when 33 feet had been lined on the left side and 79 feet on the right. A pressure of 2·3 to 2·4 atmospheres was then kept up in the workings by the use of two-thirds of the motive power during the remainder of the time that it was required. The lower galleries were carried forward to some distance beyond the dangerous ground at 983 feet from the mouth, their outer walls being constructed of the full thickness of the lower part of the finished side walls of which they formed part up to a height of 8 feet 8 inches, a further height of 8 feet 4 inches to the opening of the arch being put in by galleries driven above the lower ones in lengths of about 70 feet at a time. This work proceeded at the rate of 5 feet per day during the working period, which was, however, interrupted on four different occasions, owing to fresh fires in the lignite, causing the abandonment of the work for a time.

When the walls were finished to 1,302 feet, a rise was put at 1,286 feet, and a length of 13 feet of the arch was completed. From this point the work was carried on in both directions, but principally backwards, at the rate of about 40 feet per month of actual work. The crown of the arch, although partly in running sand, was kept sufficiently tight by timbering and closely-driven packing laths, when care was taken to insert the latter singly, and to drive each one perfectly tight before placing the next. The sand was rendered sufficiently coherent by the compressed air not to run as long as only a small surface was exposed at a time. The arch was joined up to the point where it was first stopped, in September, 1887, and the excavation of the full section and construction of the invert, which was done in face, was resumed after the "decompression" of the chamber, on September 25th, and completed to 1,476 feet at the end of October, 1888. The cost per yard of this

part of the work was £248. The full section of the finished tunnel inside is as follows:—

Height	28 feet.
Breadth at bottom	24 feet 7 inches.
„ spring of arch	26 feet 3 inches.

The further extension towards the Aisne valley was carried on from working shafts, sunk from the surface by means of metal tubbing and compressed air, which are described in a separate memoir.

H. B.

Some Cases of Wear of Steel Rails. By C. Walckenaer.

(Revue Générale des Chemins de fer, August 1889, p. 153.)

There are nine cases of exceptional and abnormal wear of Bessemer steel rails, from various manufactories, on the Western Railway of France. They were double-headed rails, 78 lbs. per yard, 5·1 inches in height, 2·44 inches wide, and 0·71 inch thick at the web. They were supported in cast-iron chairs, and joined with fishplates. They were 19·68 feet (6 metres) in length, and supported each upon eight transverse sleepers in sand ballast.

The situation and characteristics of the rails are given in a tabular statement, showing the service of each rail, lasting from ten to sixteen years. The sections of the rails are illustrated. The particulars of wear of four of the rails, from the Beauvoisine tunnel, are stated, and are reproduced in the following Table:—

Beauvoisine Tunnel.

Fig.	Situation.	Atmosphere.	Vertical Wear of Rails.		
			Top.	Bottom.	Total.
			Inch.	Inch.	Inch.
6	Curve, 1,745 yards radius; incline, up 1 in 187	Very damp	0·59	0·26	0·85
7	Curve, 1,745 yards radius; incline, up 1 in 187	„ „	0·57	0·22	0·79
8	Straight line; incline, up 1 in 187	A little damp	0·55	0·16	0·71
9	„ „ „ „ „	„ „	0·43	0·16	0·59

The wear or indentation of the rails by the action of the fishplates was very irregular in depth, varying from nothing or nearly nothing to about ¼ inch, dependent apparently upon the degree of precision of fit.

D. K. C.

Wear of Rails of Different Degrees of Hardness.

By J. W. Post.

(Revue Générale des Chemins de fer, August 1889, p. 156.)

Sixteen rails of different degrees of hardness from four different charges were submitted to observation for wear. The charges A and B contained 0·40 and 0·36 per cent., or a mean of 0·38 per cent. of carbon, and the tensile-resistance of the steel of the rails was 41·48 and 41·42 tons, or a mean of 41·45 tons per square inch. The wear of these rails was 0·76 lbs. per lineal yard. The charges E and H contained only 0·23 and 0·19 per cent., or a mean of 0·21 per cent. of carbon, and the tensile-resistance did not exceed 32·96 and 30·10 tons per square inch, or a mean of 31·53 tons. The wear of these rails was 0·97 lb. per lineal yard.

From these results it appears that the wear of the two mild-steel rails was 27 per cent. more than that of the hard rails, and that the amount of wear was nearly in the inverse ratio of the tensile-resistance of the steel. The time during which the respective wears took place was one thousand eight hundred and thirty-three days, in the course of which, at the average rate of fourteen and a quarter trains per day, a total of twenty-six thousand one hundred and twenty trains passed over the rails. Allowing a final maximum wear of 7·20 lbs. per yard, it is estimated that the hard rails would have lasted ten years longer than the mild-steel rails.

D. K. C.

Cost of Maintenance of Trial Lengths of Line laid with Metal Sleepers on the Netherlands State Railways.

(Bulletin de la Commission Internationale du Congrès des Chemins de fer, 1889, p. 1138.)

The systems of sleepers referred to in column 8 of Table (see next page) are as follows:—

I. Wrought-iron, weight 88 lbs., Vautherin cross-section, uniform throughout, 7 feet 8 inches long, 9½ inches wide. The ends are bent upwards so as to give the rail-bed an inclination of 1 in 20. Ends closed.

II. Wrought-iron, weight 104 lbs., Vautherin cross-section uniform throughout, 8 feet 2 inches long, 8¾ inches wide. Rail-bed inclined 1 in 20. Outside the rail the sleeper is bent down again to a radius of 2 feet 5 inches. Ends closed by angle-irons. Two angle-irons across underneath sleeper, 10 inches on each side of centre.

III. Mild steel, weight 110 lbs., Prussian State Railways section, uniform throughout, length 8 feet 2 inches, width 9¾ inches, bent

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
No. of Trial.	Section of Line.	Trains per day.	Gradient.	Radius of Curve.	Length of Curve.	No. of Sleepers.	System of		Date of Laying.	Date of Commencement of Record.	Cost of Maintenance in Pence per Day per Mile.						
			1 in.	Chains.	Yards.		Sleepers.	Fastenings.			1881.	1882.	1883.	1884.	1885.	1886.	Up to 1 Jan., 1887.
1	Liége-Tongres .	25	84	25	1,102	1,120	Oak	Dogs	1881	1 July, 1881	2·4	3·3	18·8	6·0	7·5	16·9	9·8
2	"	25	84	37 straight	1,134	1,133	I	A	1881	1 July, 1881	17·3	6·5	8·8	2·9	16·6	8·2	9·5
3	Bilsen-Hasselt .	25	837	straight	1,009	1,000	I	A	1881	1 Sept., 1881	29·6	12·7	28·9	3·9	13·8	5·8	14·1
6	Liége-Tongres .	25	62	50	562	600	II	B	1882	1 Jan., 1883	..	..	18·6	7·5	9·8	17·0	13·2
7	Liers Flémalle .	29	Level	50	479	500	II	B	1882	1 Jan., 1883	..	..	24·2	4·2	17·8	7·6	13·4
8	Tongres-Bilsen .	25	125	straight	504	500	II	B	1882	1 Jan., 1883	..	..	25·7	8·1	19·2	1·8	13·6
9	Bilsen-Hasselt .	25	250	straight	302	300	II	B	1882	1 Jan., 1883	..	..	25·8	13·2	14·6	4·2	14·5
11	Liége-Tongres .	25	62	18	164	201	II	B	1883	1 Oct., 1883	..	..	—	16·6	30·2	18·2	20·0
12	"	25	77	25	283	300	II	B	1883	1 Oct., 1883	..	..	—	13·6	7·1	4·0	7·6
14	"	25	62	18	1,111	1,328	III IV	A	1883	1 Oct., 1883	..	..	—	25·2	27·5	13·3	20·3
17	"	25	77	25	233	250	IV	A	1883	1 Oct., 1883	..	..	—	17·3	17·0	7·6	12·9
21	"	25	62	27	128	200	VI	B	1885	1 April, 1885	..	..	..	..	0·5	1·2	1·2
4	Hasselt-Wijchmael	14	345	straight	1,312	1,200	I	A	1881	15 June, 1881	10·1	9·1	9·4	3·0	2·4	6·4	6·5
5	Wijchmael-Achel	14	294	straight	801	800	I	A	1881	1 Sept., 1881	24·3	15·7	12·1	5·0	8·2	8·7	10·8
10	Hasselt-Wijchmael	14	256	straight	1,210	1,200	II	B	1882	1 Jan., 1883	..	..	16·5	7·3	5·0	7·7	9·1
13	"	14	154	25	376	400	II	B	1883	15 Sept., 1883	..	..	—	6·6	6·7	13·5	8·1
15	"	14	154	25	495	500	III IV	A	1883	15 Sept., 1883	..	..	—	3·8	6·3	3·9	4·2
16	Achel-Eindhoven	14	1,250	100	504	500	III	A	1883	1 March, 1884	..	..	..	4·6	2·2	5·0	4·2
18	"	14	Level	straight	504	500	IV	A	1884	1 March, 1884	..	..	..	4·6	5·4	8·1	6·2
19	"	14	1,250	straight	509	505	V	A	1884	1 March, 1884	..	..	..	8·4	13·7	4·2	8·8
20	"	14	1,000	100 straight	744	735	VI	C	1885	1 June, 1886	..	..	..	..	..	2·2	2·2

longitudinally to same form as II, ends closed, no angle-irons underneath at middle.

IV. Mild steel, weight 114½ lbs., similar to III in all respects, but with two parallel angle-irons across underneath middle, 16 inches apart.

V. Mild steel, weight 95 lbs., length 8 feet 6 inches, width 8¾ inches, Vautherin cross-section, but with raised inclined (1 in 20) rail-bed, 9¾ inches long, stamped while hot (system Hoesch-Lichthammer).

VI. Mild steel, weight 110 lbs. to 120 lbs., length 8 feet 4 inches to 8 feet 8 inches, variable cross-section on the well-known Post system.[1]

All the three systems of fastenings referred to in column 9 consist of bolt, clip to hold the rail-foot, and washer.

A. Eccentric bolt with Grover's washer above clip.

B. Ibbotson bolt, large clip with eccentric square washer between it and sleeper (system Roth and Schüler).

C. Eccentric bolt with Verona washer (roughened on both faces) above clip. Price, about 10*d.* per sleeper.

The ballast in all the twenty-one cases is either cinders, sand, or gravel. The rails are steel, 76½ lbs. per yard. The heaviest engine running over the trial-lengths weighs 50 tons, with 13½ tons on one pair of wheels. The maximum weight of a train is about 1,000 tons. The maximum speed is about 48 miles per hour. Average day's wage of a plate-layer may be taken at 1*s.* 10*d.*

In length No. 1 heavy repairs were required in 1886, and continued in 1887. Lengths Nos. 3, 5, and 9 are on marshy ground.

W. B. W.

On the Rusting of Permanent-Way in Tunnels. By W. THÖRNER.

(Stahl und Eisen, vol. ix., 1889, p. 821.)

The Author was engaged in the years 1887–8 in the technical chemical laboratory at Osnabrück, in an investigation into the causes of the rusting of the permanent-way in the tunnels of the Weilburg and Nassau Railway. The results which have been practically published in official reports now appear in full for the first time.

The tunnels in the section of line investigated are seven in number as follows:—

1. *Weilburg Tunnel*, 302 metres long, 180 metres straight at north end, 122 metres on 450 metres radius at south end. About half in coarse-grained dolerite, and the remainder in Devonian limestone and shales.

2. *Kirschhofen Tunnel*, 494 metres, 356 metres at north end on 360

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[1] Minutes of Proceedings Inst. C. E., vol. xci., p. 492.

RUST from TUNNELS.

Tunnels.	Insoluble in HCl.	Fe_2O_3.	Al_2O_3.	CaO.	MgO.	SO_3.	CO_2.	Watery Extract. Nitric Acid.	Watery Extract. Nitrous Acid.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.		
1. Weilburg: from between rail and sleeper; in a dry place	1·06	88·0	0·8	0·1	0·14	0·68	..	L	V M
Kirschhofen—									
2. From sleeper; continuous wet from dropping	4·6	5·7	3·0	36·9	6·8	0·4	40·3	T	M
3. Rust from rail on wooden sleeper; wet place	0·8	82·7	7·0	..	..	0·38	..	L	M
4. Michelsberg: rust under side of sleeper	2·3	86·5	2·3	0·3	..	0·8	..	L	M
Graeveneck—									
5. Rust between rail and sleeper	2·0	87·9	3·9	0·4	0·22	1·1	L	M	M
6. Rust last longitudinal sleeper, west side	12·9	5·3	2·9	19·6	16·5	0·6	..	T	M
7. Rusty dust outside of railhead; dry place	2·6	78·8	2·8	0·8	0·22	2·0	..	L	M
8. Between rail-foot and sleeper; dry place	21·0	56·3	4·7	1·2	0·7	1·2	..	L	M
9. Rust under side of longitudinal sleeper	2·3	87·2	2·2	..	T	1·1	..	L	V M
10. Rust under side of longitudinal sleeper	1·2	89·4	1·8	..	T	0·8	..	M	V M
Cramberg—									
11. Rust from longitudinal sleeper; near a spring	7·0	76·3	4·9	0·6	0·7	1·0	..	L	M
12. Rust No. 15 sleeper, second line	6·3	78·5	3·1	0·8	1·4	1·1	..	L	M
Obernhof—									
13. Rust, web and foot of rail in wet place	0·7	84·5	6·6	0·6	0·5	1·8	0·6	L	M
14. Longitudinal sleeper; wet place	1·7	84·6	0·8	0·4	0·2	1·1	..	..	V M
Hollrich—									
15. Rust and dust from longitudinal sleeper; very dry place	19·7	57·4	2·2	2·5	1·6	3·1	..	..	T
Lengerich—									
16. Rust from web of rail	0·8	84·3	3·9	..	..	0·6	..	M	M
17. " " foot "	1·6	86·6	1·89	..	..	0·3	..	T	L
Cochem—									
18. Rust between rail and sleeper	0·7	88·9	2·2	..	..	1·2	..	L	T
19. From rail web	2·0	83·9	1·8	..	..	2·5	0·42	L	T
Underground, London—									
20. Rust from rail head	1·8	81·3	2·0	..	0·2	2·7	..	L	V M
21. " " chair	5·0	76·3	5·0	..	0·1	4·2	..	T	V M

T = traces, L = little, M = much V M = very much.

metres radius, 138 metres straight. Ground generally similar to No. 1.

3. *Graeveneck Tunnel*, 127 metres long, straight entirely in sound greenstone with columnar structure at either end, above which the village of Graeveneck is built. This, although one of the shortest tunnels, shows the strongest rusting. The rock contains no carbonate of lime.

4. *Michelsberg Tunnel*, 345 metres, 30 metres straight at north end, 304 metres on 340 metres curved in the middle, 11 metres straight at south end.

5. *Cramberg Tunnel*, 732 metres, 163 metres on 360 metres radius at west end, 357 metres straight in the middle, 232 metres on 360 metres radius at south-west end.

6. *Obernhof Tunnel*, 450 metres straight.

7. *Hollrich Tunnel*, 318 metres on 360 metres curve.

In addition to the above, samples of rust were taken from the following localities:—

8. *Lengerich Tunnel*. Wanne and Bremen railway 765 metres long, entirely in cretaceous marls containing 80 per cent. of carbonate of lime. The rusting is very slight.

9. *Cochem Tunnel*. Berlin and Metz railway 4,200 metres long, in Devonian schists poor in lime.

10. *Underground Railway*, London. (Locality not stated.)

Samples of rust, both from rails and sleepers, as well as of the drainage water, mud, and calcareous deposits in the tunnels, were taken from all of these localities and carefully analysed. The results, so far as the rails and sleepers are concerned, are contained in the following Tables.

In some instances the upper dusty layer of the rust analysed above was scraped off and specially examined. The numbers correspond with those in the preceding Table.

Tunnels.	Insoluble in HCl.	Fe_2O_3.	Al_2O_3.	CaO.	MgO.	SO_3.	CO_2.	Watery Exhaust.	
								Nitric Acid.	Nitrous Acid.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.		
5. Graeveneck. . . .	38·6	40·5	4·6	1·6	1·1	2·1	..	M	
12. Cramberg	59·8	19·5	4·5	5·0	0·5	1·2	L	T	M
14. Obernhof	44·1	36·9	4·4	1·2	0·7	2·0	..	L	V M
17. Lengerich	52·4	33·7	1·2	0·6	..	1·1	..	..	M
19. Cochem	48·4	38·2	1·9	0·6	0·4	2·4	..	L	T
21. Underground, London	34·0	39·1	4·1	2·2	0·3	7·9	..	T	V M

On comparing these results it appears that the composition of rust in tunnels, apart from Nos. 2 and 6, which, being the result of calcareous infiltrations, may be regarded as ferruginous stalagmite, is

substantially similar from all localities. The essential constituent is ferric oxide, partly present as hydrate, with variable, but always small quantities of silica, alumina, lime, and magnesia; carbonic acid, when present, being in connection with the two latter bases. The only abnormal constituent is sulphuric acid, or, more correctly, an oxidized sulphur compound, which occurs in all proportions from 0·3 to 7·9 per cent., the actual state of combination being doubtful. Most probably it is in the form of basic ferric sulphate. Nearly all the samples show a slightly acid reaction, but only give a very small amount of sulphuric acid when exhausted with water. No rust contains iron as sulphide.

The origin of the sulphuric acid may be most readily ascribed to the oxidation of sulphurous acid derived from sulphur in coal and dissolved in the condensed steam from locomotives. This, trickling down the walls, is absorbed by the ballast and slowly oxidized by atmospheric air, producing sulphuric acid, which, penetrating to the rails by capillarity, attacks them, forming ferrous and ferric sulphates.

This, however, does not account entirely for the result, as samples of rust taken from rails in sections of the line open to the air, as well as from many different samples of ironwork from town buildings, and also newly formed rust obtained by exposure of clean iron wire to air and rain in a garden at Osnabrück, contained sulphuric acid in quantities (0·8 to 5·5 per cent.),[1] quite comparable to those observed in the tunnels; and in these cases the sulphurous acid in the exhaust steam of the locomotives could not contribute, except in a very indirect manner. A further series of experiments showed that nitrous acid and nitrites are formed by the direct action of iron upon air and water, and these substances are well known to act most energetically in the conversion of sulphurous into sulphuric acid. A more potent cause has, however, been discovered by the Author in the existence of free sulphuric acid in the exhaust steam of a locomotive which was determined experimentally on a heavy goods engine travelling at the speed of 30 miles per hour. The absorption apparatus consisted of a large Woolf bottle, half filled with water for taking up sulphuric acid and ammonia, a second tube with a solution of sulphate of cadmium, for detecting sulphuretted hydrogen, and a third with a solution of iodine in iodide of potassium for collecting and oxidizing sulphurous acid.

The apparatus was placed in front of the smoke-box of the engine, and connected on one side with the funnel by a tin tube, and on the other with a steam-jet aspirator, allowing a continuous current of the gases and steam to pass through. Towards the end of the trial the steam-jet connection was closed so as to leave the absorption vessels full of gas, which was afterwards collected and analysed. The results of two trials, each of one hour's duration, gave:—

[1] Details of these and numerous other analyses are given in the original, p. 825. —H. B.

Composition of Incondensable Chimney Gases.

—	Volumes per cent.	
	6th October.	15th November.
Carbonic Acid	5·4	6·1
Oxygen	13·4	13·0
Nitrogen	81·5	80·9
Carbonic oxide	0·0	0·0
Sulphurous acid	0·0	0·0

The water in the Woolf bottle contained free sulphuric acid, ammonia, and ferric oxide, but no nitrous oxide. No sulphuretted hydrogen was detected, but the third tube, as might be imagined, contained a considerable amount of sulphuric acid due to the oxidation of the sulphurous acid which was emitted in large quantity.

The amount of sulphuric acid evolved per hour by the engine was estimated by the Author, after deducting that required to saturate the small proportion of ammonia present, at 2,228 grammes, or very nearly 5 lbs., a quantity which under appropriate conditions is likely to act very destructively upon ironwork. The action is likely to be strongest in tunnels where the rock is not very wet, and the exhaust steam is without means of rapid escape, and especially in those where the rock is poor in carbonate of lime. Where the ground is very wet and provision is made for drainage, the soluble gases are taken up by the water, and removed in a very diluted form, before they have much chance of doing harm. Carbonate of lime acts beneficially by directly neutralizing the sulphuric acid, and converting it into gypsum.

The heaviest rusting seems to take place between rail and sleeper when both are of iron, the acid water being introduced by capillary action, forms layers of rust which by continual accretion attains a thickness of 10 to 15 millimetres, and drives rail and sleeper upward; wooden sleepers, on the other hand, protect the iron on account of their low conductivity, which prevents the precipitation of the acid gases, if the surface of the latter is sufficiently covered up in the ballast.

The methods best suited for the prevention of rusting in tunnels seems to be as follows:—

1. Covering the ironwork as far as possible with heavy or so-called carbonized tar (not ordinary gas tar) or asphalt. These are excellent preservatives if applied to the metal in a properly clean condition and renewed at intervals.

2. The precipitation being greatest at the coldest points in the tunnel, that is on the ironwork, the latter should as far as possible

be covered up with ballast, leaving only the rail head exposed; small limestone ballast is best suited for this purpose.

3. In very wet tunnels provision must be made for drainage, so as to keep the bed as dry as possible.

4. When the rock is poor in carbonate of lime, the ground should be completely covered with small limestone fragments, or when that is not sufficient, the roof and walls should be lime-washed from time to time. Simply sprinkling the ground with milk of lime the Author does not consider to be desirable, as in dry places it is likely to produce dust prejudicial alike to passengers and officials.

5. The engines should make as little exhaust steam as possible in tunnels, and dispense with its use wherever it can be done.

In conclusion the Author hopes that the unexpected results that he has obtained in this investigation may lead to a possible study of the subject by others.

H. B.

Increasing the Weight of Rails in Long Tunnels on the St. Gothard Railway.

(Glaser's Annalen für Gewerbe und Bauwesen, 1889, p. 120.)

In the seventeenth Report of the Directors of the above railway it is stated that the life of the rails in long and ill-ventilated tunnels is scarcely one-third of their duration in the open air. It has, therefore, been decided in lieu of the normal rails 130 millimetres high, weighing 37 kilograms per metre (74·6 lbs. per yard), to substitute for them in tunnels heavier rails 142 millimetres high and weighing 44 kilograms per metre (88·7 lbs. per yard). That there is a practical economy in this step is shown by the following calculation, from which also it is evident that the saving effected by increasing the weight of the rails is all the greater in proportion to the assumed rate of wear, and, therefore, in proportion to the density of traffic.

Total height of rail		130 millimetres			142 millimetres		
Total permissible wear		10 ,,			16 ,,		
Assumed annual wear	millimetres	1·0	0·75	0·5	1·0	0·75	0·5
Total life of rails	years	10	13⅓	20	16	21⅓	32
Probable duration	,,	8	11	16½	13	17½	26½
Cost of 2 kilometres of rails	francs		12,500 (£500)			15,000 (£600)	
Annual interest and sinking fund at 4 per cent.	,,	1,790	1,410	1,060	1,500	1,220	920
The annual saving obtained by the use of the heavier rail is thus	,,	..	..	..	290	190	140
Or expressed as a percentage	per cent.	..	..	..	19	16	15

G. R. R.

Railway Workshops: their Design and Construction.
By J. Davis Barnett, M. Can. Soc. C.E.

(Transactions of the Canadian Society of Civil Engineers, 1889, p. 151, 2 plates.)

Beginning with "location," the Author strongly recommends that more than enough land should be purchased in the first instance, even if it afterwards has to be sold for building lots.

Foundations.—For northern climates it is better that the sides of foundation-walls should be sloped rather than stepped, so as to prevent the earth from gripping the wall, which is injurious in case of frost. Pillar-footings and column-bases, when above floor-level, are usually based on sheet-lead; the Author is of opinion that the running in, between base and cope-stone, of a fine cement grout would be quite as effective and certainly cheaper. An instance of the use of iron to reduce the first cost of foundation is to be seen in the new erecting-shop of the Grand Trunk Railway at Stratford, where, instead of making continuous walls to carry the rails supporting the traverser-table, it was found less costly and quite as efficient to build disconnected piers and span them with wrought-iron beams of I section. These beams carry the rails laid upon them longitudinally, and support the flooring laid transversely.

Walls.—It is best to use bold pilasters or large piers to receive all roof- and floor-beams; setting them so that they stand out prominently, and spanning the panels between them with comparatively thin bonded walls, free from bats if of brick. This method of straight lines and prominent offsets would be of pronounced value in localizing and absorbing the vibrations received from the roof or the machinery, and would result in shops having a less ugly appearance and a longer safe life.

Engine-houses or Locomotive-sheds.—In America the ordinary arrangement is an annulus, or segment of an annulus, whose centre is that of the unroofed turn-table. With this construction is combined a narrow trussed ridge-roof or a so-called flat-roof (angle 5°) offering little obstruction to the wind, and permitting the use of an inexpensive roof-covering. A flat roof supported by pillars gives a very stiff building for the limited amount of material used, if sloped inwards the roof-drainage is a simple matter. The stack of the locomotive naturally going to the higher part of the building brings its front end close to the outer wall containing the windows, so that most light is received where it is needed—on the moving parts of the machine. In the sparsely-settled districts of America, segmental engine-houses of wood with flat gravel-covered roofs are common. They can be built for £170 per stall, the foundation consisting of cedar posts 6 or 8 feet apart, with a mud sill on which rests a pine frame of 6- to 8-inch square scantlings, the roof being single sheeted with 1- or 1½-inch tongued boards and coated with paper-felt, tar and gravel; the ashpit,

25 feet long, being of brick or stone, and one iron smoke-jack being provided. The shell of a similarly roofed building with brick walls and stone foundation costs about £200 per stall. In Canada, slate is rarely used for shop roof-coverings, although the native slates are well adapted for the purpose, being very compact and non-absorbent of water. The fire risk from a roof covered with shingles—set in cement and occasionally lime-washed—is very slight; in fact, it is probable that shingles so treated are safer than slate. Referring to the longitudinal saw-tooth roofed engine-houses of the English type, it is stated that the use of this form of roof is not possible in Canada, on account of snow and frost, the Author only knowing of one single instance of its occurrence on the American Continent north of New Jersey. Where longitudinal houses are used, the Canadian substitute for the saw-tooth roof is the single slope ("flat"), or single ridge of quick pitch. An example of this type of engine-house is that built by the Grand Trunk Railway Company at Montreal. This is 76 feet wide by 282 feet long, with five parallel tracks, accommodating twenty-five long tender-engines. The Author devotes considerable space to a comparison of the relative advantages of round and longitudinal engine-houses, citing instances of each kind. On the whole, American opinion seems to favour the round house, but the Author strongly endorses the longitudinal type as eminently serviceable where a large number of engines have to be turned out, almost together, during the busy portion of the day. Many engine-houses are now equipped with a continuous 1½- or 2-inch pipe, having branches to each stall and flexible couplings to each engine. Its uses are various. The steam and water from a boiler to be "blown off" and washed out are sometimes used to heat the water with which the washing out is done. The pipe may be passed into a boiler of cold water, so as to shorten the time required for raising steam. Sometimes the pipe is connected with the jet-blower at the base of a locomotive chimney, and the steam used in creating a draught to quicken the newly-lit fire.

Oil-house.—A special feature of American engine-houses is a detached oil-house; a fire-proof brick structure with iron roof, roof-covering, and shutters, and floor of concrete or asphalt. Underneath it are iron storage reservoirs, with inlet pipes so arranged that oil received in bulk can gravitate from the tank-car into any of them. Thence it is lifted by hand- or steam-pump into small tanks on the upper floor, and is drawn thence by tap for engine or train use. The cellarage is warmed by steam-pipe from outside, and gas or electric light is used, no lamp or torch being admitted.

Sand-house.—From 8 to 10 tons of sand for increasing adhesion of driving-wheels are issued daily at central stations, and large quantities have consequently to be stored, the Columbus (Ohio) sand-store having a capacity of 1,000 tons. The building is of wood, with hinged shutters at top to permit the air to assist in sand-drying. The floor is of dry brick, set on edge with a tile

drain below. When required for use, the top layer of sand is shovelled into hoppers containing 1-inch pipes circulating live steam and spaced $2\frac{1}{4}$ inches apart. When dry the sand falls through an opening in the bottom on to a concrete floor. The Grank Trunk Railway Company has recently employed belt and bucket elevators worked by hand-power for delivering the sand to the box on top of the locomotive.

Coal-shoots are mentioned, but the Author considers that the varying local necessities do not permit any uniformity in this matter.

General repairing- or erecting-shops.—The consideration which governs the amount of floor-space is the time required to repair an engine. In America a common average is: For heavy repairs, equivalent to a wear of 100,000 miles, 90 days; for medium repairs (70,000 miles), 60 days; for light or specific repairs (30,000 miles), 30 days; general average, 60 days for a wear of 67,000 miles. On this basis, the Author is of opinion that there should be stall-room in the repair-shop for 10 or 11 per cent. of the total engine stock. It may be expected that 4 or 5 per cent. will be in the paint-shop going out, and that 5 per cent. are having their boilers washed out, or undergoing trifling repairs, not requiring them to enter the shop. This leaves 80 per cent. of the motive power effective and at work daily.

The Author next deals with, in succession, traversers, overhead travelling-cranes, the transmission of power, machine-grouping, foundry, brass foundry, smiths' shop and boiler-shop, the particulars given referring for the most part to ordinary practice. He then describes various constructions of floors for workshops. A continuous concrete floor used at Columbus (Ohio) has for its foundations 6 inches of broken stone, then 8 inches of finely-broken stone mixed with cement, and for the surface, a compound 4 inches deep of Portland cement, asphalt and sand, which, being slightly elastic, is not readily cracked. South and West of Philadelphia, a solid floor is made by rolling the earth and then bedding half round locust stringers, spaced 30 inches apart, in 4 inches of concrete. The stringers are floored with 2-inch pine plank. Oak flooring is often used in that neighbourhood, being cheaper than white pine in the local market. The Georgia Central Railway insulates the floors of its shops from the damp earth by running in rosin. In Canada a cheap floor for light weights is made by bedding half-round cedar in a foot of engine-cinders, and nailing 2-inch pine plank on top.

Turntables.—The American pattern of turntable is a "top-deck" structure of cast-iron up to the common diameter of 60 feet. The weight of table and load is carried on a single fixed central pyramid, with an anti-friction cap on the top. No gearing is used; a short lever or hand-spike stands out from one end, and two men are usually sufficient to walk the table and its load around. Turntables of 100 feet in diameter are invariably of wrought-iron with deep side girders, the load being carried on the bottom deck. The

motive-power is usually an independent boiler and engine, running on the ring-rail and coupled to one end of the table by drag-links or other special form of adjusting connection. Particulars are given of the mode adopted by the Author for putting in the foundations of a 50-foot turntable in running sand.

Car-shops.—The roofed space required for repairs of freight-cars is severally limited, as 25 per cent. of the work can be done in the open air. The annular form of car-shop, with radial tracks, is occasionally used in America, requiring a turn-table of exceptional dimensions, usually 100 feet in diameter, to permit, not only of a coach or two freight-cars, but also of the small tank-locomotive doing the shunting to turn upon it. There are certain points in favour of the annular form of car-shop if it is intended exclusively for new construction, but the Author prefers the longitudinal freight-car shop, which is of the simplest construction, often wide enough for six or seven parallel tracks and from 200 to 500 feet long.

Warming and Ventilation.—Certain workshops, as paint-shops, need special provision for warming and ventilation. A successful arrangement is the use of a fan to draw air through a nest of small steam-pipes, and then to force the warm air into a light galvanized iron tube, from which it is passed into overhead branch pipes, and delivered through slide gratings below controlled by the workmen. Particulars are given of the application of this system at the Columbus paint-shops; also of a similar method adopted for widely scattered shops at Cleveland (Ohio), by Mr. J. Walker.

The Paper concludes with some considerations on the general disposition of railway workshops, many examples of European and American practice being cited. There are two Appendixes giving the relative area of railway shops for the locomotive and car departments respectively, on the lines mentioned in the text.

A discussion followed the reading of the Paper, chiefly directed to the relative advantages of the round and longitudinal types of engine- and car-house, the prevailing opinion appearing to favour the longitudinal form.

F. G. D.

The Nogent Tramways worked with Compressed Air.

By Maurice Demoulin.

(Revue Générale des Chemins de fer, Sept. 1889, p. 264.)

This is a system of tramways, comprising a length of 7·44 miles now open, commencing at Vincennes, following the road from Vincennes to Nogent and Ville-Evrard, and comprising numerous inclines up to gradients of 1 in 19. The rails are laid to the ordinary gauge, sometimes on the footpaths or the side-slopes, sometimes on the pavement. For side-slopes a flat foot-rail is employed, weighing 40½ lbs. per yard, laid on transverse oak

sleepers at 34½ inches pitch. The total weight of metal in the way is 69 lbs. per yard. The way is laid on ballast from 14 to 16 inches deep. The way laid on the road consists of steel rails 21¼ feet long, of unsymmetrical section, with guard rails of the same section weighing 56 lbs. per yard. The width of interspace is 1·14 inch on the straight portions, 1·38 inch on curves. The rails are supported on cast-iron chairs 4¼ inches wide, spiked to oak transverse sleepers at 3 feet 4 inches pitch. The joints are fished and fastened with bolts and Grover's spring washers. The rails are kept to gauge by means of cross-ties, three to each length of rail. The angle of the crossings is 10°, and the curves are of 115 feet radius. The turntables are 9 feet 2 inches in diameter, and are laid on concrete 12 inches thick. The minimum radius of curvature, independent of the turnouts, is 131 feet (40 metres). The maximum inclines are 1 in 22 and 1 in 19.

The stations at Porte-Jaune and Gournay consist of a simple covered bench. Others are of light brickwork covered with tiles, and having a floor superficies of 130 square feet.

The cost per lineal yard of the various systems of way is approximately as follows:—

	Per Yard. s.	d.
1. Flat-foot rail on footpath	15	3
2. " " with gutter stones and footpath	21	9
3. Unsymmetrical way, with broken stone road	45	9
4. " " " stone pavement	26	1½
5. " " " on 6 inches of concrete with paving in cement mortar	50	10

To include the cost for indemnities, deviation of drains, and other general charges, one-fifth is to be added to the prices above given.

The air-compressors now working are installed at Maltournée and Vincennes. They are on the system known as *étagé*, or in two stages of compression, in two single-acting pumps, by which pressures of from 40 to 45 atmospheres are obtained. The first pump delivers the air at an absolute pressure of 7 atmospheres to the second pump, in which it is raised to 46 atmospheres absolute. On leaving the pump the air is passed through a desiccator to separate any of the water employed for cooling which may be delivered with it prior to entering the accumulator. The compressors are horizontal; the two pistons are on one rod, which is connected to a crank-shaft driven by a steam-engine. 1 lb. of compressed air at 45 atmospheres is obtained by the consumption of 2½ lbs. of steam.

The leading dimensions of the air-compressor at Maltournée are as follows:—

Diameter of the pumps	15 inches.
Stroke " "	5·91 "
Diameter of the steam-cylinder	13·78 "
Stroke of the piston	27·60 "
Pressure of the steam	5 atmospheres.
Number of turns per minute	66
Weight of air compressed to 45 atmospheres per hour	397 lbs.

In ordinary working the compressed air is cut off at 15 per cent. of the stroke. There are three air compressors, of which two are at work at one time. There are two machines at Vincennes.

The cars are constructed with an imperial or upper floor. They are self-propelling, having four coupled wheels 5¼ feet apart between centres. The under frames are of plate-iron, with laminated springs. The body, of wood and iron, rests directly on the frames, 16 feet 5 inches long, 6¼ feet wide outside. It is constructed with twenty-one places inside, twenty-four outside, six on the platform—in all, fifty-one persons. The car is 24 feet 10 inches long over all, and it weighs, complete, 20 tons. An ordinary car, constructed for one hundred passengers, weighs 2½ tons. The cylinders of the self-propelling cars are outside, 6½ inches in diameter, with a stroke of 11 inches, and 29½-inch wheels. Walschaert's valve-gear is employed. Nine cylindrical air-reservoirs, 22½ inches in diameter, are placed under the floor of the car transversely, having a total capacity of about 110 cubic feet, capable of holding 374 lbs. of compressed air of 45 atmospheres pressure. The hot-water reservoir can hold 7 cubic feet.

The results of working in 1888 show that 81,072 miles were run. The gross receipts amounted to £6,829, and the expenses to £4,125, or 72 per cent. of the receipts. The number of passengers was one hundred and seventy-nine thousand one hundred and thirty-four.

D. K. C.

Compound Locomotive on the Northern Railway of France.

By A. Pulin.

(Revue Générale des Chemins de fer, August 1889, p. 164.)

Mr. Sauvage designed a six-coupled wheel compound locomotive, No. 3,101, which was put to work in August 1887. It has six coupled wheels and a pair of leading wheels. It has three cylinders in line across the engine, of which the first or high-pressure cylinder, which is steam-jacketed, is inside, and the two second cylinders for expansion are outside the longitudinal frame-plates. The two spaces between the first cylinder and the two others are occupied by receivers, into which the steam is exhausted from the first cylinder, to the right and the left, and from which it is admitted into the other cylinders. The three cylinders are all connected to one driving-axle, the middle one of the three coupled-axles, the crank of the high-pressure cylinder bisecting the right angle formed by the cranks of the two outer cylinders.

The high-pressure cylinder is 17 inches in diameter, the two low-pressure cylinders are 19·7 inches in diameter, and the length of the stroke is 27·56 inches. The connecting-rods are 6 feet 11 inches long, or six times the length of the crank. The coupled-

wheels are 5 feet 5 inches in diameter, and the leading wheels 3 feet 3½ inches. The area of fire-grate is 22½ square feet, and there are 1,223 square feet of heating surface, or 54·4 times the grate-area. The working pressure is 13 atmospheres.

The previous experience with No. 701 locomotive, a compound engine of four cylinders,[1] showed that excessive compression of the steam in the first cylinder was not only a cause of loss of power, but also an obstacle to free running at high speed. This objection has been removed in No. 3,101, by providing a greater proportion of clearance-space, and means of removing the slide-valve transversely on the valve face of the cylinder, whereby with the aid of oblique ports and a separate expansion valve, the cut-off could be varied without altering the travel of the valve, and for greater expansions without incurring excessive compression.

The weight of No. 3,101, empty, is 43 tons; in working order 46½ tons, of which there is 40 tons of driving weight. The net maximum tractive force is estimated at 6 tons, which is $\frac{1}{6.6}$ part of the adhesion weight.

The engine No. 3,101 was tried for tractive power and efficiency on the Lens-La Chapelle line, in March 1889, with a train of forty-two wagons, weighing 618 tons. The inclines of 1 in 200, which prevail nearly all the way from Creil to Survilliers, were ascended at the speed of 12½ miles per hour. The average tractive force was 4·428 tons, corresponding to 16·86 pounds per ton. From these data it appears that the average work done at the draw-bar of the tender was 327·5 HP. Indicator diagrams were taken during the trial, mostly on the inclines of 1 in 200; and as the speed was nearly uniform, the efficiency of the engine may be calculated approximately. The highest indicator power was 446½ HP.; and the average work utilized at the draw-bar was 327½ HP., as before stated, corresponding to an average indicator power of 430 HP. Making allowance for the resistance of the tender and the dynamometrical car, of about 31½ HP., the total power transmitted from the locomotive at the draw-bar of the tender amounted to 359 HP.; and the difference (430–359=) 71 HP. is the passive-resistances of the locomotive as a carriage and of the mechanism, or 16½ per cent., leaving an efficiency of 83½ per cent. If to this be added 2·8 per cent. representing the resistance as a vehicle, the efficiency of the mechanism would amount to 86·3 per cent.; a degree of efficiency showing that there is no material reduction of efficiency in the compound locomotive compared with ordinary locomotives.

From the steam-jacket on the high pressure cylinder, a small quantity of condensed steam, only from 1⅓ gallon to 2⅔ gallons, was collected per hour,—in a ratio varying inversely with the extent of admission employed.

D. K. C.

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[1] Minutes of Proceedings Inst. C.E., vol. xcvi. p. 417.

A New kind of Auxiliary Cylinder applied to Link-Motion Reversing-Gears.

(Portefeuille Économique des Machines, 1889, p. 170.)

Mr. Fouquemberg, a Belgian engineer, has invented a very simple arrangement of auxiliary cylinder, capable of many applications, and especially adapted for attachment to link-motion reversing-gears. The apparatus consists of a hand-lever of the usual form, with an eccentric forged on the lower end. A strap on this eccentric is connected with the slide-valve rod of the auxiliary cylinder; through this eccentric passes a weigh-shaft upon which another eccentric is formed. The eccentric on the hand-lever forms the strap for this inner eccentric. At both ends of the weigh-shaft a lever is forged, one of which is connected with the usual weigh-shaft and suspension links of the link-motion; the other is connected with the piston-rod of the auxiliary cylinder. The action is as follows: when the hand-lever is moved from the position of mid-gear, its eccentric moves the slide-valve of the auxiliary cylinder, and admits steam to one side of the piston, the piston moves forward, and with it the arms of the weigh-shaft; the eccentric on this weigh-shaft is so arranged that by this forward motion it moves the slide-valve back, so that the steam is cut off and the piston stops; thus the auxiliary piston follows the motion of the hand-lever in either direction, but stops directly the hand-lever ceases to be moved. The only work done by the engine-driver is that which is necessary to overcome the friction of the auxiliary slide-valve and eccentric. In order that the piston may stop directly the valve moves back, it is so arranged that the valve comes to a position where both steam-ports are covered from steam, but are open to the exhaust, so that any steam left in the cylinder escapes directly into the air. Buffer stops are provided to prevent the lever coming too hard upon the end of the sector-plates; and catches of the usual type are provided, one of which enables the engine-driver to add his force to that of the cylinder if necessary. This arrangement has been applied to locomotives on the Belgian railways, and on the Orleans Company's railways in France. Other varieties of this gear are described, and the article is illustrated by figures showing one or two applications.

H. H. P. P.

Experiments made at New York to determine the Relative Economic Efficiency of three different kinds of Water-Pumps. By B. F. Isherwood, Chief-Engineer U.S.N.[1]

These experiments were made in 1867 at the New York Navy Yard, with the object of ascertaining the weight of water lifted a given height per lb. weight of steam expended. The pumps used

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[1] The original is in the Library Inst. C.E.

were a reciprocating, a rotary, and a steam siphon-pump. The two first pumped water into and out of the boilers, and also from the vessel overboard; the siphon-pump was constructed for the latter purpose only. The experiments were conducted by Mr. Clark Fisher, U.S.N., under the direction of Chief-Engineer Isherwood, but although made in 1867, they were not published till 1889.

In the reciprocating pump, the steam-cylinder is 9 inches in diameter, with a 6-inch stroke, and the diameter of the steam piston-rod 1¾ inch. The steam-cylinder is horizontal, and works without expansion or condensation, and the valve is driven by an eccentric. The pump is 5 inches diameter; its rod is a prolongation of the piston-rod, the stroke being the same. The steam- and pump-cylinders and flywheel-shaft are all on the same foundation-plate. The flywheel-shaft is driven by an open connecting-rod in two parts. The pump has a large air-chamber. The suction-main is 2¾ inches in diameter, and 3 feet 7 inches long. The discharging-nozzle was originally of the same diameter, but for the purposes of the experiment it was reduced to 1½ inch, in order to make it correspond with the discharge-orifice of the rotary pump, the diameter of which was also 1½ inch. In practice, however, this plan was not found to work well, the pressure upon the piston of the reciprocating-pump being too great. The diameter of the discharge-pipes of the two pumps ought not to be equal. The discharge from the rotary pump being regular it will, with a pipe-diameter of 1½ inch, deliver the same quantity of water in a given time as the reciprocating-pump with a pipe-diameter of 2¾ inches, because the latter is intermittent in its action. The length of pipe in the reciprocating-pump was 28 feet, and the mean velocity of the water in the pump and in the discharge-pipe as 1·00 to 10·43.

The rotary pump is of cast-iron, with the necessary passages, and the two ends are separate from, but communicate with, the water-cavity. A spindle with stuffing-boxes passes through them, and moves an inner revolving cylinder. The axes of this cylinder and of the cavity do not coincide, and the point where they touch is made watertight by a brass packing-ring. On one side of this point the water enters through a pipe 2 inches in diameter; on the other it is discharged through another, 1½ inch in diameter. Within the cylinder are three pistons, dividing the circle into three parts. As the inner circle revolves, the pistons are carried round with it, and at the same time they move in and out against the periphery of the cavity, notwithstanding the eccentricity of the axis of the inner cylinder. Thus they both force the water before them, and receive it into the space behind them. This method requires no valves, produces a continuous discharge, and is as positive in its action as that of the reciprocating-pump. The water-cavity is 7 inches diameter, and 5 inches broad. The pistons displace 109 cubic inches per revolution, and the length of the suction-main is 5 feet 5 inches, and of the discharge-pipe 28 feet. The rotary pump was worked by the same steam-cylinder as the

reciprocating pump. A strap was carried from the fly-wheel to a pulley on the spindle of the pump, and as the diameters of the fly-wheel and the pulley were as $2 \cdot 3$ to $1 \cdot 0$, the pump made $1 \cdot 15$ revolutions per stroke of the steam-piston.

The steam siphon-pump is simply one of the applications of the Giffard Injector. It is constructed as follows: Two suction-mains, or pipes, 2 inches in diameter, are screwed at an angle of 42° into a hollow brass sphere $5\frac{3}{8}$ inches diameter. Between them is a nozzle for the steam-jet; its upper end is $\frac{1}{3}$ of an inch above the centre of the sphere, while the lower, to which the steam-pipe is attached, passes below it. Above this a nozzle for the discharge-pipe is screwed into the sphere, shaped like an inverted cone, the lower diameter being $1\frac{1}{8}$ inch, and the upper 2 inches; it is $4\frac{1}{2}$ inches long, and the discharge-pipe, 22 feet long, is attached to it. During the three trials, three different nozzles for the steam-jet were used. All were of the same height, $6\frac{3}{4}$ inches, and of the same inner lower diameter of $1\frac{1}{4}$ inch, but the upper inner diameters were successively $\frac{3}{4}$, $\frac{5}{8}$, and $\frac{9}{16}$ of an inch, according to the boiler-pressure of 20, 30, or 40 lbs. per square inch. The water-discharge was of course continuous. The diameter of the steam-pipe was $1\frac{1}{2}$ inch.

In making the experiments, all the pumps were supplied with steam from the same boiler. The feed-water was pumped into the boiler by a small auxiliary steam-pump, after being carefully measured. The exhaust steam from the auxiliary pump was discharged back into the tank supplying it. Thus the measured feed-water correctly represented the weight of steam used in the cylinder for the pumps, although the auxiliary pump was worked from the same boiler.

Before an experiment, all the tanks, pumps, and boiler were thoroughly tested for leakage. The boiler and steam-pipes were felted.

In the supply-tank, the water was admitted in such a way as to keep it at a certain level during the experiments. It was in all cases raised to a height of 17 feet 8 inches; the discharge-pipe was $1\frac{1}{2}$ inch in diameter, 28 feet long for the rotary and reciprocal pumps, and 22 feet long for the siphon. The water was delivered into two receiving-tanks, each holding exactly 160 cubic feet; they were placed side by side on an elevated platform, and carefully levelled. As the cost of the experiments was determined by the weight of feed-water pumped, the weight of coal consumed was not measured. The experiments with the reciprocating and rotary pumps lasted seventy-two hours. With the siphon-pump three experiments of twenty-four hours each were made, in order to ascertain the effect of working it with steam of different pressures, as mentioned above. Every hour there were taken the average temperature of the air outside, and within the experimenting shed, of the water in the supply- and receiving-tanks, height of barometer, and steam-pressure in the boiler. The operator also recorded the number of strokes or revolutions per

hour of the pumps, and number of lbs. of feed-water pumped into the boiler. The exact time at which each receiving-tank was emptied was noted, and at the end of each experiment the water in the boiler was left at the same height, and with the same steam-pressure as at the beginning.

Results of the Experiments.

(Height of water, 17 feet 8 inches.)

I. Reciprocating-pump—

Duration of trial, seventy-two hours.
Total cubic feet of water lifted, 52,240 feet.
Number of lbs. of water raised per lb. of steam, 135·6 lbs.

II. Rotary pump—

Duration of trial, seventy-two hours.
Total cubic feet of water lifted, 45,280 feet.
Number of lbs. of water raised per lb. of steam, 108·6 lbs.

III. Steam siphon-pump—

Duration of trial: three trials of twenty-four hours each.
Total cubic feet of water lifted: First trial, 7,840; second trial, 9,760; third trial, 9,440.
Number of lbs. of water raised per lb. of steam: First trial, 29·6 lbs.; second trial, 37·3 lbs.; third trial, 37·4 lbs.

It must be remembered that the weight of water lifted by the siphon-pump is not only that lifted from the supply-tank, but also the weight of feed-water pumped into the boiler.

In comparing the results, the Author begins with the steam siphon-pump. This pump was found to work very badly with a pressure of 20 lbs., but acted perfectly when pressures of 30 lbs. and 40 lbs. were applied. The duty in the two last cases varied but slightly, and taking their mean as the correct performance, there would result 661 lbs., of water raised 1 foot high, for every lb. weight of steam used. As this duty includes the weight of steam expended, it represents the total dynamic effect produced by the steam.

The duty with the reciprocating-pump was 2,397 lbs. of water, raised 1 foot high by 1 lb. of steam, or 3·6 times greater than that of the siphon, including with the latter the lb. of steam itself. In this case, however, the steam was used without expansion, and with such high back-pressure that only 43 per cent. of the total pressure could be utilized. But if a very small condensing steam cylinder were used, the total IHP. would be obtained for about 40 lbs. of steam per hour. The pressure being 38 lbs. per square inch, 86 per cent. would be utilized, and the duty in water raised per lb. of steam would be in the ratio of 4·8 to that of the siphon. Where the economy of fuel is of importance, it is evident that any competition of the siphon-pump with the reciprocating-pump is hopeless. The former can only be used advantageously on a steamer to pump out its bilge, after the vessel has come to anchor, with steam in the boilers, or when there is no further use for the main engines. It is very cheap, cannot become deranged, requires

no attention, and can be placed wherever there is room for a pipe of a few inches diameter.

If the duty of the reciprocating and rotary pumps be compared, the marked inferiority of the latter will at once be seen. The pressures with the two pumps were not the same, the mean total pressure with the rotary being less than that with the reciprocating-pump, while the back- and friction-pressures were alike in both pumps. Hence less pressure was utilized with the former than with the latter, and the duty of the reciprocating-pump was therefore 1·14 greater than that of the rotary pump. Some allowance must, however, be made for the friction caused by the strap from the engine, by which the rotary-pump was worked, as also the resistance of the valves in the reciprocating-pump. If all accessory disturbing influences are eliminated, the duty of the two pumps will be found to approximate more closely.

The permanent cause of inferiority in the rotary-pump lies chiefly in the greater water-leakage past its pistons. Nor can this pump, with its uniformly revolving pistons, fill with water the same proportion of space displacement as the reciprocating-pump with its piston coming to a state of rest at the end of its stroke. Hence, while 0·86 of water was displaced by its piston, and discharged by the reciprocating-pump, the rotary pump discharged only 0·57 of the water displaced by its piston.

B. D.

Notes on New Types of Hydraulic Lifts: Samain's System.

By G. Cerbeland.

(Portefeuille Économique des Machines, 1889, p. 34.)

The types of hydraulic lifts in general use in high buildings are often inconvenient, from requiring deep wells to be sunk for the reception of the long cylinders, and they also require complicated and expensive foundations. When of the direct type requiring a cylinder of the same length, or, indeed, rather longer than the height of the lift, their application is limited, and also the consumption of water under pressure is not always proportionate to the work done.

To avoid these defects many improvements have been introduced, amongst which are those of Mr. Samain. With regard to the usual direct type, composed essentially of a long cylinder fitted with a ram, to the upper end of which the cabin is attached, the ram moving vertically in the cylinder, the latter being fixed in a well of suitable depth, Mr. Samain makes the ram hollow; to economise weight, the top of the hollow ram is sealed, but the lower end is left open. The water under pressure passes through a distributor, the use of which is to admit water to the cylinder, to raise the cabin, or stop the flow, and to hold the ram at any height, or lastly, to let the water flow out of the cylinder and let the ram down. Thus

constructed the lift is a very simple machine, but it is always inconvenient, one difficulty being to balance the dead weight of the ram and cabin without loss of water. The solution of this difficult problem is sometimes effected by a counterpoise nearly equal to the dead weight of cabin and ram. But the problem is complex, and it is necessary to remark that, supposing the pressure of the supply-water to be constant, the pressure exerted on the inferior surface of the ram will vary considerably according to the position of the ram itself; at the lowest position (taken at the ground-level), it will be augmented by the depth of the well, and diminished in proportion to the rise of the ram; or otherwise the ram behaves as a float more or less constrained to displace a variable quantity of liquid, and is submitted to a corresponding variation of pressure. Mr. Samain uses a hollow ram open at the lower end, and as the water fills the whole interior of the ram up to the top, the cabin may be said to rest on the column of water, it is obvious that as the ram rises, the effective pressure decreases by an amount corresponding to the rise of the ram. In order to equalize this pressure without increasing the size of the ram, Mr. Samain has devised a regulator or compensator consisting of a cylinder fitted with a piston, from which latter a band composed of metallic leaves passes through a stuffing-box in the cylinder cover, and thence over a large pulley; a counterbalance is attached to the other end of the metallic band. The capacity of the cylinder is slightly in excess of the total displacement of the ram in the lift-cylinder, but is not so long. The pulley is eccentric, and the axle turns in carriages running upon rollers; the eccentric-pulley is constrained to move concentrically with its circumference by means of two rollers. The supply-water under pressure is admitted from the distributor to the under side of the piston, and the top of the cylinder is connected to the ram-cylinder of the lift. The action is as follows: the water under pressure being admitted below the piston, the latter rises and displaces the water above it, which in turn raises the ram of the lift; the eccentric-pulley makes one-half revolution for the total lift, and the axle being eccentric with the rim of the pulley, as the latter turns, the leverage on the counterbalance side increases, and on the piston side decreases, thus a very perfect balance is effected; as the lift descends the opposite action takes place. The consumption of water is reduced to a minimum; it is equal to the volume of the compensator cylinder, and in consequence of the open hollow ram, and the fact that the cabin is supported almost directly on the water, all the moving parts can be made lighter than usual. The description is illustrated by a plate with several figures showing the compensation. The figures also show in detail the ram of a telescopic hydraulic lift, also of Mr. Samain's design.

H. H. P. P.

Experiments with a Compound Winding-Engine at the Skalley, Shaft I Colliery, Saarbrücken.

By — Schmelzer.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, 1889, p. 191, one plate.)

The compound engine under notice was originally a single horizontal winding-engine, with a 43·3-inch cylinder, by 5 feet 1·8 inch stroke, winding two full tubs, each weighing 10 cwts., from a depth of 1,115½ feet, with a steam-pressure of 44·12 lbs. per square inch. In 1886 in Dingler's engine-works in Zweibrücken the engine was altered to a compound one, to suit an increased steam-pressure of 95½ lbs. per square inch, by adding a second cylinder 31½ inches diameter. Until the new boilers were in working order, the engine had to be so made to act as a double-cylinder engine, with a pressure of 3 to 4 atmospheres, but it was found unnecessary to use the engine except as a compound one. The engine winds four tubs at a time in two decks, each tub weighing when full 10 cwts. nearly, from a depth of 372 yards, assisted by a counterbalance rope under the cage, weighing 8·06 lbs. per yard. In order to show the advantage of the compound system here introduced, the Author gives, together with the experiments of this engine, experiments with two other winding-engines (see next page).

Engines No. II and III were counterbalanced with rope under cage. The consumption of fuel per HP. per hour is 40 per cent. less by the compound than by the double winding-engine at Skalley shaft, No. II. Expansion is obtained in the compound-engine without any special mechanism, and in a certain degree by the unequal cylinders and the reversing lever. The Author points out that with the compound-engine less heating surface is necessary, consequently there is a saving in boilers, stokers and repairs. The plate contains diagrams of the engine. The whole winding is done in forty seconds, the average speed per second being 27·89 feet, and the average piston speed 4·95 feet per second. The engine is fitted with a receiver, from which live steam can be supplied to the low-pressure cylinder if required; this also assists the engineman in lifting the reversing-lever. The engine works observably quietly. A table, showing experiments with seven winding-engines, of which four are compound, all made at the Dingler's engine-works, finishes the Paper.

No.	—	I. Double engine, cyl. diam. 34 ins. Stroke, 5·15 feet. Colliery, Heinitz. Depth, 153 yards.	II. Compound engine. Skalley Shaft No. 1. Depth, 372 yards.	III. Double engine, 28½ inches diameter. Stroke 5·15 feet. Skalley Shaft No. II. Depth 439·6 yards.
1	Duration of experiment	6	6·5	4·5
2	Number of tubs raised	1,200	1,121	315
3	Average useful weight raised per winding in lbs.	4,409·24	4,612·06	2,526·49
4	Total consumption of fuel in lbs.	5,833·43	5,401·32	3,196·70
5	Feed-water used in lbs.	39,683·20	40,430·57	25,000·37
6	Feed-water temperature ° Fahr.	104	154·4	111·20
7	Boiler-pressure in lbs. per sq. in.	44·118	82·35	51·47
8	Feed-water reduced to 32° Fahr., and steam from 212° Fahr. in lbs.	39,758·27	40,333·78	25,048·21
9	Useful HP. reduced upon one second	51·83	113·6	59·8
10	Fuel consumption gross per hour per useful HP. in lbs.	18·74	7·31	11·88
11	Ditto including the steam feed-pump ,,	18·74	7·31	12·31
12	Feed-water consumption per hour per useful HP. ,,	127·60	54·76	92·90
13	Ditto including the steam feed-pump ,,	,,	,,	96·34
14	Feed-water consumption per hour per HP. reduced to 32° Fahr. and steam from 212° Fahr.	127·84	54·63	96·52
15	Number of boilers in use	3	2	2
16	Their construction	Lancashire	Lancashire	Lancashire
17	Heating-surface in sq. feet.	2,099·04	1,119·49	1,481·17
18	Fire-grate area ,, ,,	77·50	45·21	60·28
19	Evaporation per square foot of heating-surface per hour in lbs.	3·16	5·58	3·75
20	Fuel consumption per square foot of fire-grate per hour ,,	12·59	18·37	11·77
21	Lbs. of water evaporated per lb. of fuel	6·8	7·52	7·82

C. Z. B.

On Hand-Power Diamond-Boring Machines.

By G. Nordenström.

(Jern Kontorets Annaler. 1888, p. 161.)
(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, xxxvii., p. 468.)

The use of bore-holes as a means of discovery of ore-deposits in underground workings has been practised in the Swedish iron-mines for a considerable time, notably at Dalkarlsberg, where thirty or forty years ago search-holes were driven by the ordinary method of percussion hand-boring with drill and sledge, to distances of as much as 44 feet, which however was the maximum attainable; and even then the direction was restricted, as it was not possible to bore overhead for more than a short distance, as the work had to be done dry. In 1872 the method of diamond-boring was adopted by E. Erdmann for investigating the subterranean development of the coal-bearing rocks of Scania, and in the three years following about 1,100 yards of borings were put down by foreign companies, at an average cost of £6 5*s.* per yard—for which price shafts could have been sunk in the same ground. Subsequently, in 1886, a Swedish company adopted an American prospecting machine, driven by compressed air, in the Norberg mines, where a "cross-cut" boring, inclined upwards at a slope of 1 in 100, was driven through granite, felstone, and limestone for a distance of 33 yards, and discovered two ore-beds of 5 and 8 feet thickness respectively. The average length driven per shift was 8 feet 8 inches, the maximum of 16 feet having been attained in the limestone. Other borings of a similar character, varying in direction, were put down in adjacent mines, measuring in all about 220 yards, at an average rate of 7·73 feet per shift. The cost, although considerably less than that of the first diamond-boring machine, was still almost the same as that for which levels could be driven at the rate of wages current in the district, so that the only saving was in the time required. This is mainly due to the cost of driving, most of the Swedish iron-ore mines being without facilities of obtaining steam, or any large amount of water-power. In 1887 a simplified machine, suited for manual power, was introduced. This differs principally from the earlier ones in its dimensions, which are smaller, and in the substitution of a ratchet lever for hydraulic pressure in the feed-motion. The boring-rods are iron tubes of 33 millimetres external, and 25 millimetres internal diameter, 1·5 metre long, screwed together. Eight diamonds, four inside and four outside, are used in the boring head, which is of 24 millimetres bore, giving cores of 22 millimetres diameter. The average weight of the diamonds between 0·75 and 0·8 carat each, and the cost last year about £2 14*s.* per carat. The total weight of the machinery, including 55 yards of rods and the force-pump and gear for flushing the hole, is 14 to 15 cwts. The

first of these machines was set to work in the St. John's mine, at Norberg, in May 1887, and since that time a further number, making eight in all, have been introduced by the prospecting company in other districts, including the mines of Rőrås, Wiegelsbo, Dannemora, Bersbo and Vinkårn. Up to the end of 1888 a total length of 3,250 yards of borings had been carried out. In 1887 the number was 127, of an average depth of 65 feet, the maximum being 183 feet in one of the Norberg mines. In the present year this has been exceeded, a distance of 200 feet from the face having been reached in the Alabama mine at Persberg. Of this, 190 feet were bored in fifty-nine and a half shifts, after which the progress was considerably slower, the boring-gear having suffered considerably from the heavy shocks to which it was subjected.

Only 7 per cent. of the borings started from the surface, the remainder having been carried out at various depths underground. As regards direction, 25 per cent. were vertically downwards; 37 per cent. nearly horizontal, and 38 per cent. varied between 58° upwards to 78° downwards. Notwithstanding this great diversity in direction, no difference in working effect could be perceived, the machine doing as well in one direction as another.

For working the machine from four to six men are required; namely, two or four for turning the rods, which is effected by winch handles and conical gear-wheels; one for the flushing-pump, and a foreman, who directs the work and replaces the diamonds when necessary. Two men at the handles are sufficient up to depths of 68 feet, but it is better to work with four at all times, so as to obtain greater speed. The machine is of course driven less rapidly than when steam-power is employed, the number of rotations being reduced from 200 to 400, to 60 to 70 per minute. About 1¼ gallon of water per minute is required for flushing out the hole.

The rate of advance realized in the shift of eight to nine hours, varied between 2½ feet and 4¾ feet; the average in 1888 being 3½ feet, mostly in very hard rock. By adopting a double-shift system, from 50 to 60 yards per month might be easily obtained. which, under the ordinary conditions of work in the district, would be from thirteen to sixteen times as much as could be obtained by driving levels.

The charge made by the Prospecting Company for the use, maintenance, and supervision of the machine, is at the rate of about 17*s.* 6*d.* per yard; the wages of the three or five men required for working it being at the charge of the same. Under these conditions, the total cost is from £1 6*s.* 6*d.* to £1 8*s.* 6*d.* per yard; while that of driving levels, including that of lifting the waste to the surface, may be taken to vary from £2 15*s.* or £3 3*s.* per yard in ordinary, to £3 17*s.* 6*d.* per yard in very close ground.

The results of these explorations have, as a whole, been satisfactory; the discoveries include a deposit of copper ore, 12 feet

thick, at Rőras; an important mass of iron-ore at Wintjernsfeld, 100 feet below the bottom of an abandoned mine, and several others, of great thickness and longitudinal extension, at Dannemora, on the ground separating the mines now at work.

H. B.

Geothermometric Measurements in the Boreholes at Schladebach and Sennewitz. By — Köbrich.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, 1889, p. 171.)

The borehole at Schladebach, near Kötschau, was begun in August 1880 by the Prussian State Mining Department, its primary object being to seek the source of the brine springs of Dürrenberg, and to further prove a coal-seam, the existence of which had been discovered by a former borehole, which, however, was abandoned at a depth of 2,820 feet in the Lower Red Sandstone (Rothliegende). At the point selected for the hole, a tower, 108 feet high, was erected, which admitted of boring rods of 65 feet long being used. The apparatus was arranged to work on different systems, as the nature of the rock required; but that most employed was the diamond drill. The machinery was driven by a 25 HP. portable engine. The depth attained in the borehole was 5,734 feet. It began with a diameter of 11·2 inches, which was decreased in steps, as the work progressed, until it finally reached 1·25 inch.

At the suggestion of Dr. Huyssen measurements of temperature in the hole were begun in December 1884, when a depth of 4,513 feet had already been reached. Observations were taken at intervals of 98·4 feet throughout the entire depth. The increase of temperature with the depth was found to be remarkably uniform. The average increase for each observation was 1·44° Fahrenheit (1° = 67·3 feet). The temperature recorded at a depth of 19·5 feet, where the Author assumes surface influence ceases, was 50·45°, and that, at the extreme depth of 5,734 feet, 133·88° Fahrenheit, a rise of 83·43° Fahrenheit. The results of the observations have been tabulated by the Author, from which he deduces the following formula—

$$T = 50 \cdot 45 + \frac{D - 19 \cdot 68}{67 \cdot 30}.$$

T being the temperature in degrees Fahrenheit at any depth D measured in feet.

The borehole at Sennewitz, begun in July 1883, was undertaken in search of coal measures, which were expected to be in close connection with the Porphyry formations of the neighbourhood. At a depth of 105 feet, having passed through the Tertiary clay, the younger Porphyry was encountered, under which lay the Lower Red Sandstone, and then, the older Porphyry formation,

which was penetrated for 3,969 feet, when the hole was abandoned, at a depth of 4,766 feet, still in the same formation. At depths of 1,544 feet and 1,971 feet, brine springs were met, the former containing 10·5 per cent., and the latter 13·10 per cent. of salt. Owing to the occurrence of these springs the increase of temperature was very irregular, but when the disturbing influences ceased to play an important part, the regularity was restored—1° F. being equal to a depth of 66·84 feet. The Author gives the following Table comparing these measurements with those made in other boreholes:—

—	Name.	Total Depth.	Depths from which Calculations were made.	Number of Observations.	Depth equal to 1° Fahrenheit.
		Feet.	Feet.		Feet.
I.	Schladebach	5,734	19–5,734	387	67·3
II.	Sennewitz	4,766	2,473–3,515	96	66·8
III.	Lieth	4,388	1,396–4,139	17	64·0
IV.	Sudenburg	..	98–1,863	19	59·4
V.	Sperenberg	4,065	721–3,496	9	58·7

The instrument employed in the measurements of temperature was a modification of Magnus' Geothermometer. It consisted of an ordinary thermometer having an opening at the end of the tube. Before using, it is completely filled with mercury, at a temperature less than that required to be measured, so that, when lowered into the borehole, a portion of the mercury column, corresponding to the temperature, is driven out through the opening in the end of the tube. After remaining from twelve to fourteen hours in the hole, it is withdrawn and placed in a water bath, the temperature of which is gradually raised until the mercury reaches the point of overflowing, when the temperature of the bath is accurately read, by a standard thermometer, this being the temperature of the hole required. In order to withstand the extreme pressure, which was as much as 169 atmospheres, the instrument was enclosed in a stout steel tube. The Paper is accompanied by a set of diagramatic curves representing the temperature at different depths.

H. L. C.

Mining-progress in Prussia during the year 1888.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, 1889, p. 121, with 2 plates.)

The improvements and experimental researches made in mining is a subject dealt with yearly by the Prussian Government, and the article under notice deals with fourteen subjects, beginning with tools and ending with steam-engines. Experiments carried out in the districts of Siegen I. and Diez with the explosive roburite have shown that it is one-third less powerful than dynamite, and that the gases after explosion are very injurious to workmen. Carbonite is also unfavourably reported upon as regards the health of the workmen using it. Under the head of haulage, mention is made that at the fiscal collieries in Saarbrücken all haulage planes have been ordered to have an inclination towards the workings of 1 in 200 instead of 1 in 500, for the purpose of diminishing the cost of haulage and ensuring a better drainage. Under the head of ventilation a novel method of carrying air into the faces of workings by means of air-pipes made of sailcloth or canvas hose and varnished is described. Also, in the fiscal collieries of Saarbrücken, various methods of dealing with coal-dust in the workings are described. At the Camphausen Colliery over 13,000 yards of water-piping have been laid, wherever coal-dust is found to lie. The water is pumped into a receiver, which is placed some distance up the shaft in order to obtain a head of water. The pipes in the shaft are 3 inches in diameter; in the workings they are 2 inches, and at the places where the water is sprinkled $\frac{3}{4}$ inch in diameter. In every working place a 5-yards-long india-rubber hose-pipe is used, fitted with a spray. Besides diminishing the risk of coal-dust explosions, other advantages are claimed for watering the working faces, such as—the workmen are not troubled so much from the disagreeableness of breathing fine dust, the safety-lamps are not dulled too much, the temperature is lessened, and small quantities of fire-damp that may collect are dispersed with the currents of air caused by the playing of the water. Besides, in all the haulage- and air-roads sprays are introduced, two at each place, at one-third and two-thirds of the height of the gallery respectively, 50 yards apart. At present eighty such sprays are in use, which expend 6,000 cubic feet of water per day. Similar arrangements are described which exist at the collieries Dudweiler and Kreuzgräben, in Saarbrücken.

In Upper Silesia, at the Königin Luise Colliery, the Schanschieff portable primary-battery electric lamp has been tried with success. The lamp weighs 3·3 lbs. when uncharged, and 4·6 lbs. when charged, costs 30*s.* 6*d.*, and costs about 1*d.* per hour when burning.

C. Z. B.

Production of Prussian Mines during the year 1888.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, 1889, p. 1.)

——	Number of Works or Mines.	Output.	Value.	Persons employed.
		Tons.	£.	
1. *Coal and Bitumen.*				
a. Coal	352	59,475,351	14,595,947	198,222
b. Lignite	419	13,207,888	1,607,967	23,408
c. Graphite	..	..	..	..
d. Asphalt	4	10,747	5,069	47
e. Mineral oils	8	2,770	19,688	122
Total	783	72,696,756	16,228,671	221,799
2. *Mineral Salts.*				
a. Rock-salt	5	188,692	45,184	283
b. Kainite	5	257,557	186,707	..
c. Other potassium salts	6	723,182	369,007	3,870
d. Kieserite	2	11,152	4,380	..
e. Boracite	6	148	2,430	..
Total	24	1,180,731	607,708	4,153
3. *Ores.*				
a. Iron	553	4,145,254	1,277,001	26,214
b. Tin	60	666,700	686,392	13,748
c. Lead	118	143,384	804,800	14,283
d. Copper	22	521,873	862,003	14,379
e. Silver and gold	3	63	2,061	154
f. Zinc	..	..	..	..
g. Mercury	..	..	..	..
h. Cobalt	1	33	198	14
i. Nickel	3	9	67	..
k. Antimony	..	..	..	..
l. Arsenic	3	1,198	3,619	128
m. Manganese	26	27,308	30,677	518
n. Bismuth	..	..	..	..
o. Uranium ores	..	..	..	..
p. Pyrites	11	99,305	37,307	432
q. Other sulphate and alum ores	1	211	61	2
Total	801	5,605,338	3,704,186	69,872
Grand total	1,608	79,482,825	20,540,565	295,824
Charcoal pig-iron	..	22,065	139,357	..
Coke pig-iron	..	3,076,691	7,002,254	..
Total pig-iron	..	3,098,756	7,141,611	..
Block tin	..	133,280	2,178,900	..
Block lead	..	89,864	1,148,587	..
Block copper	..	18,900	1,380,745	..

C. Z. B.

Prussian Mining Accidents during the Year 1888.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, 1889, p. 33.)

—	1888.			1887.			Average of the last Twenty-two Years.		
	No. of Persons Em-ployed.	Deaths by Acci-dent.	Per 1,000 Em-ployed.	No. of Persons Em-ployed.	Deaths by Acci-dent.	Per 1,000 Em-ployed.	No. of Persons Em-ployed.	Deaths by Acci-dent.	Per 1,000 Em-ployed.
Coal-mining	198,963	544	2·734	191,379	513	2·681	155,751	464	2·979
Lignite-mining	23,408	50	2·136	23,266	58	2·493	19,076	45	2·359
Ore-mining .	66,193	77	1·163	63,660	70	1·100	62,142	85	1·368
Other mining	10,566	25	2·366	10,089	22	2·180	7,790	14	1·797
Total . .	299,130	696	2·327	288,394	663	2·299	244,759	608	2·484

Table IV shows the number of accidents divided under twenty-four heads, from which the following is taken :—

—	Coal-Mining.		Lignite-Mining.	
	Deaths by Accident.	Per 1,000 Men employed.	Deaths by Accident.	Per 1,000 Men employed.
By blasting	26	0·131	0	0
By falls of stone and coal	217	1·091	24	1·025
On inclines and brake staples . . .	57	0·286	1	0·043
In shafts	54	0·271	4	0·171
On haulage roads	29	0·146	0	0
By explosions of firedamp	71	0·357	0	0
In bad gases	13	0·065	0	0
By machinery	10	0·050	1	0·043
By drowning	0	0	1	0·043
On the surface	56	0·281	18	0·769
Sundry causes	11	0·055	1	0·043
Total	544	2·734	50	2·136

Statistics are also given of non-fatal accidents in cases where the injured persons could not return to work for a month and more. Special statistics are also given of accidents by explosion of firedamp. The number of explosions in 1888 amounted to eighty-eight, of which nineteen were attended with fatal results. The

largest number, twelve, of the fatal explosions, occurred in Westphalia, resulting in the loss of eighteen lives. The most serious explosion, by which forty-two persons were killed, occurred in Saarbrücken, at the Kreuzgräben Colliery.

Again, the colliery explosion accidents are analysed by Tables showing the general circumstances of these collieries, such as the number of seams worked, the kind of coal raised, the system of working, the system of ventilation, position of the accidents, depths of the mines, time of the accidents, in which month, day of the week, time of day, in which shift, at what time during the shift, kind of weather, height of the barometer and thermometer—by far the most accidents occurred during a high atmospheric pressure—the force and direction of the wind, and the cause of the accident.

C. Z. B.

Wages earned by Persons employed in Mining in Prussia during 1888.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, 1889, p. 76.)

Districts.	Underground. Miners or Hewers, and Persons employed in Haulage.					Underground. Sundry Workmen.				
	Number of Persons employed.	Duration of Shift from Bank to Bank.	Wages per Shift.	Wages per Annum.		Number of Persons employed.	Duration of Shift from Surface to Surface.	Wages per Shift.	Wages per Annum.	
		Hours.	*s.*	£.	*s.*		Hours.	*s.*	£.	*s.*
Coal-mining, Upper Silesia	25,010	12·0[1]	2·07	28	5	4,749	12·0[1]	1·91	27	18
,, ,, Lower ,,	8,066	10·0[2]	2·18	33	7	1,867	10·0[2]	2·13	33	12
Lignite-mining, district of Halle	7,833	11·8	2·45	36	1	853	11·6	2·11	31	1
Cupriferous-slate mining, district of Halle . . .	10,749	8·8	2·75	38	19	140	8·9	2·63	39	18
Rock-salt mining, ditto .	2,430	8·5	3·11	45	5	210	8·5	3·47	55	15
Fiscal-ore mines, Upper Harz	1,896	10·7	2·27	33	10	417	12·0	2·54	38	0
Coal-mining, Dortmund district	65,967	6–12	2·96	46	16	14,852	6–12	2·34	38	3
Coal-mining, fiscal mines, Saarbrücken	17,338	10·0	3·06	44	5	3,010	10·0	2·60	39	5

[1] Also 8 and 10 hours. [2] Also 12 and 8 hours.

Districts.	Surface. Exclusive of the young Persons and Females. Number of Persons employed.	Length of Shift from Surface to Surface.	Wages per Shift.	Wages per Annum.	Young Persons from Fourteen to Sixteen Years of Age. Number of Persons employed.	Length of Shift.	Wages per Shift.	Wages per Annum.
		Hours.	s.	£. s.		Hours.	s.	£. s.
Coal-mining, Upper Silesia	6,832	12·0[1]	1·68	24 18	150	12·0[1]	0·70	9 2
" " Lower "	3,213	10·0[2]	1·89	29 14	377	10·0[2]	0·90	13 14
Lignite-mining, district of Halle	9,904	11·9	2·13	31 5	217	10·5	1·21	16 9
Cupriferous-slate mining, district of Halle	2,053	9·1	2·58	38 4	562	8·3	1·12	15 10
Rock-salt mining, ditto	950	11·6	3·02	48 16	98	11·1	1·09	16 8
Fiscal-ore mines, Upper Harz	984	12·0	1·55	23 15	244	10·0	0·63	8 18
Coal-mining, Dortmund district	17,548	8–12	2·37	39 17	3,828	8–12	1·01	15 6
Coal-mining, fiscal mines, Saarbrücken	3,949	10·0	2·55	35 11	105	8–10	1·19	16 11

Districts.	Females. Persons employed.	Length of Shift.	Wages per Shift.	Wages per Annum.	Totals and Averages. Persons employed.	Length of Shift.	Wages per Shift.	Wages per Annum.
		Hours.	s.	£. s.		Hours.	s.	£. s.
Coal-mining, Upper Silesia	4,129	12·0[1]	0·77	10 13	40,870	12·0[1]	1·85	25 16
" " Lower "	451	10–12	1·11	17 5	13,974	10·0[2]	2·04	31 10
Lignite-mining, district of Halle	483	11·7	1·32	17 9	19,290	11·8	2·23	32 13
Cupriferous-slate mining, district of Halle	..	..	..	..	13,504	8·8	2·66	37 17
Rock-salt mining, ditto	1	11·8	1·20	21 5	3,689	9·4	3·05	46 0
Fiscal-ore mines, Upper Harz	..	..	..	..	3,541	11·2	1·99	29 12
Coal-mining, Dortmund district	..	..	..	..	102,195	6–12	2·69	43 3
Coal-mining, fiscal mines, Saarbrücken	..	..	..	..	24,402	10·0	2·92	42 2

NOTE.—By wages are understood the net wages, after deducting all work charges, as also provident-fund and sick-fund charges. The amounts of the deductions are shown in the Paper.

[1] Also 8 and 10 hours. [2] Also 12 and 8 hours.

C. Z. B.

Testing the Atmosphere of Mines at Kolscheid near Aachen.

By — KAETHER.

(Zeitschrift für das Berg-, Hütten- und Salinen-Wesen, 1889, p. 116.)

The object of these experiments was to determine how the height of the barometer influenced the composition of mine-atmospheres. . In the ventilating shaft a gasometer was placed, which was arranged to fill in about twelve hours. By this means an average sample was obtained.

Readings of the barometer were taken at midday and midnight, and samples morning and evening. The determination of marsh gas and carbonic-acid gas, were made with Coquillon's "Grisometer." This apparatus, briefly described, consisted of an arrangement of three glass tubes communicating with each other; one containing a solution of sodium hydrate, the other fitted for electrically acting on the gas, and the third graduated for measuring the diminution of volume during the experiments. A known volume of the sample and air, having been introduced into the measuring tube, are brought into contact with the solution of sodium hydrate, which dissolves the free carbonic acid gas, the following reaction taking place:—

$$CO_2 + 2\ Na\ OH = Na_2\ CO_2 + H_2O$$

The diminution of volume having been measured, the gas is admitted into the electrifying tube and exposed to the action of a glowing spiral of paladium wire. The marsh gas is decomposed as follows:—

$$CH_4 + 2O_2 = CO_2 + 2H_2O.$$

The resulting gases are again treated with the solution of sodium hydrate, when the newly formed carbonic acid gas is dissolved. From the second diminution of volume the quantity of marsh gas is estimated. The results obtained by this process are accurate enough for all practical purposes, and compare favourably with the more exact analysis made by Winkler's method as shown below.

——	Winkler, per cent. of CH_4.	Coquillon, per cent. of CH_4.
27th June . .	2·51	2·53
28th June . .	2·41	2·10
29th June . .	2·11	2·10
30th June . .	1·77	1·80

H. L. C.

Graphite-mining in Bohemia. By A. PALLAUSCH.

(Berg- und Hüttenmann. Jahrbuch der k.k. Bergakademien, Leoben, 1889, p. 95.)

The graphite district of South Bohemia, in the neighbourhood of Przisnitz and Eggetschlag, extends over an area 14 miles long and 10 miles wide. The graphite occurs in the form of lenticular or irregular deposits embedded in gneiss. The beds vary in thickness from a few inches to more than 20 yards. In one mine as many as five parallel beds have been observed. The graphite is usually rendered very impure by admixed gneiss, kaolin, and iron pyrites. Both hard and soft varieties are met with, the purest containing 80 to 95 per cent. of carbon. The Author traces the history of the mining industry from the year 1767, when mining operations were commenced by the peasants, until 1811, when Prince Schwarzenberg began mining on a large scale. In 1888, in addition to the Prince's mines, the only ones in active operation are those of Porak Brothers and of the Mugrau Company.

The largest and deepest of Prince Schwarzenberg's mines works the so-called Florian bed, which has been explored for a length of more than 600 yards by means of four shafts varying in depth from 144 to 262 feet. Workings are now being carried on at the fourth, fifth, and sixth levels, headings being driven across the deposit so as to form pillars 20 yards apart. Beginning at the lowest point, these are worked on both sides by over-hand stoping. The excavations, which require to be supported by strong timbering, are then filled in. The soft graphite obtained with the pick is at once sorted into three classes. The best variety, characterized by its softness, purity, intense black colour, and metallic lustre, and the second variety are brought to the surface in boxes holding 44 lbs. The third variety and the hard graphite are transported in mine-trucks.

The treatment of the graphite from the different mines varies according to the quality of the mineral. The two best classes, brought in boxes from the mine, are taken into a well-lighted sorting-house, where each piece is broken and carefully freed from impurities (kaolin, iron ochre, and pyrites). The graphite is then dried on a steam-heated boiler-plate, and packed in barrels ready for the market. Other classes of soft and hard graphite are refined. The mineral is crushed in a roller-mill with excess of water, and the resulting mud is passed through six separating tanks, 5 feet long by 3½ feet broad by 3½ feet deep, and thence through a number (usually eighteen) of depositing tanks, 20 feet long, 3½ feet broad, and 5 feet deep, until the graphite slime attains a given height. When the slime has settled and become compact, the supernatant water is drawn off, and the slime is transferred to a tank, provided with a stirrer, and thence is forced by pumps at a pressure of 6 atmospheres into large filter-presses. Each press is emptied three to four times in twelve hours and yields 396 to 529 lbs. of graphite in tabular cakes containing 20 per cent. of

moisture. These cakes are finally dried by being exposed to heated air at a temperature of about 190° Fahrenheit for twenty-four to thirty hours. Two drying-rooms are used, each holding 20 tons, so that while the drying operation is in progress in one, the other is cooled, emptied, and refilled with moist graphite. When the weather is favourable the cakes are dried in the sun. The selling price of the pure graphite varies from £1 10*s.* to £20 per ton, and that of the refined product from 16*s.* to £8 per ton. The production of graphite in Prince Schwarzenberg's works, in 1888, amounted to 6,753·5 tons, valued at £17,850. The total production of the district has increased from 7,129 tons in 1880 to 11,790 tons, valued at £23,470, in 1888.

B. H. B.

Mining and Metallurgy in Australia. By H. A. Gordon.

(Mining Machinery and Treatment of Ores in Australian Colonies. Reports on Mining Machinery at the Melbourne Exhibition; on Mining and Plants for the Reduction and Treatment of Ores in the Australian Colonies; and on Processes adopted in America for Treatment of Auriferous and Argentiferous Ores. Wellington, New Zealand, 1889.)[1]

At the request of the Minister of Mines for New Zealand, the Author visited the Melbourne Exhibition and the Australian colonies, and reported on the machinery best adapted for working the mines of New Zealand and for reducing the various ores. In his report, which is illustrated with one hundred and fifty-eight drawings, the subjects are dealt with under the following heads: crushing and pulverizing machinery, ore-concentrators, chlorination, rock drills, water augers, steam-boilers, pumping-machinery, mineral railways, new explosives, machinery at the Mount Bischoff tin mine, Broken Hill mine and works (where the plant is a duplicate of the ore-dressing machinery used at Lake Superior and Anaconda copper mines, in the United States), zinc desilverization process at the Dry Creek smelting works, Adelaide, and a description, abstracted from Prof. T. Egleston's work on the metallurgy of gold, of the processes used for extracting metals from the ore at the Boston and Colorado works, in the United States. There is also an Appendix, containing a report by Prof. W. C. Roberts-Austen on the Freiberg metallurgical process.

Although the quartz-reduction mills, and other machinery reported on, are new to Australia, they have already been described in the English technical journals. The Mount Bischoff tin mine[2] is situated on the western slope of Mount Bischoff, forty-nine miles from Emu Bay, Tasmania. The tin ore appears to be confined to a basin, 1,400 feet in diameter. The plant at the mine comprises one stone-breaker, seventy-five heads of

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[1] The original is in the Library of the Institution.

[2] Transactions of the Mining Association and Institute of Cornwall, vol. ii., 1888, p. 51.

stamps, thirty classifying pyramidal boxes, thirty jiggers, seventeen Kayser buddles, twenty-three single- and twelve double-convex revolving-tables. The whole of the works are lighted up with electric glow-lamps. The quantity of clean ore produced during the first half of 1888 amounted to 1,266½ tons. The ore from the mine is conveyed to the stone-breaker, and thence to the stamping-battery, where it is stamped until it passes through a grating having 144 to 169 holes to the square inch. The ore is then classified, the classification being effected for the coarser and richer ore by revolving trommels, or by a series of reciprocating screens, one above the other, and for fine sands by self-acting classifying boxes. There are two sets of these boxes for every five heads of stamps, one for the coarse material and one for the fine sand. From the bottom of the pyramidal boxes, the sand passes through a 1-inch gas-pipe to the jiggers. These are furnished with screens and bedding suitable for the fineness of the material that enters them. The bedding consists of crop-tin, the thickness depending on the quality of the material treated. For rich ore the bedding is thin, but for poor sand a thicker layer is required. The speed of the jiggers varies from 60 to 220 strokes per minute. Ore passing through a 144-mesh requires 144 to 160 strokes per minute, whilst that passing through a 169-mesh requires 200 to 220 strokes. Two forms of buddle are employed, one for the slimes and one for coarse sand. The latter is termed a Kayser buddle. In principle it is similar to the ordinary buddle. It is, however, provided with revolving arms, carrying the scrapers, hinged near the centre, underneath the main arms, whilst the outer extremity is held in position by a screw. The hinged arm may be raised or lowered to the exact height required. Instead of the brushes of the ordinary buddle, the Kayser buddle has scrapers. It is 20 feet in diameter, and concave in shape. The mixture of water and sand is distributed at the periphery by eight gas-pipes. The heavy sulphides remain, while the light sand passes down the bottom of the buddles, and is discharged over the circular riffle at the centre. One buddle will concentrate the ore from ten heads of stamps, 8 cubic feet of water being required per minute. For the treatment of slimes, the convex table is used, and has proved the best concentrator for the purpose. In this case, the process is continuous. The proper working of the table, however, depends largely upon the construction, particularly upon the even and smooth surface of the sixteen equal sections of wood of which it is composed. Recently, tables with a 1-inch coating of Portland cement have given great satisfaction. The convex tables have a diameter of 16 feet, and an inclination of 1 in 12. In the tables recently erected, two are built on one shaft.

B. H. B.

Gold-Mining in Transylvania. By E. Thilo.

(Berg- und Hüttenmannische Zeitung, 1889, p. 125.)

The gold-mining centres of Transylvania are the towns of Brád, Abrudbanya (the *Auraria major* of the Romans), and Zalatna (*Auraria minor*). Mining is here carried on under great difficulties. The mines are situated at considerable distances from the railway, the roads are bad, wood is scarce and dear, and the water-supply is defective. In the vicinity of Brád, some beds of lignite occur, but the fuel is of poor quality. Gold is widely distributed throughout the region, but rarely in payable quantities. The gold in the ore seldom amounts to 19 dwt. per ton.

The ore is treated in primitive stamping batteries. An overshot water-wheel drives six or twelve rectangular wooden stamps, 4 feet 6 inches to 6 feet 6 inches in length. The shoes are of iron, or, in some cases, of basalt. The mortar-boxes are of wood, lined with iron or basalt. The ore is shovelled into the mortar-box, and stamped while a stream of water runs through. The muddy water passes out either into a sump, where the heavy particles sink, or over an inclined plane covered with blankets, that serve to retain the gold. Most of the gold remains in the mortar-box, and the process is ocasionally interrupted in order to put the stamped residue through a hand-sieve. The fine material that passes through then proceeds to a primitive concentrator, consisting of an inclined table, having a surface of 10 square feet, over which water slowly flows, and on which the material is continually shovelled up against the stream until all the particles of gangue are washed away. Below this concentrator there is another inclined table, covered with blanket, to catch any particles of gold that escape. The material thus caught is treated again, and the gold is finally separated out of the concentrates on a wooden vanning shovel. The stamping process is very slow, twelve stamps treating only 4 tons in a week. The loss of gold, however, is very slight, and notwithstanding the constant handling of the material, the treatment is remarkably inexpensive, not more than 10*d.* being paid for stamping a ton of ore, and 1*s.* for washing the pulverized material. The total cost per ton thus amounts to 1*s.* 10*d.* The cost of the stamps is less than £20. Owing to want of water, they can rarely be worked for more than six months in the year.

More scientific methods are adopted at the larger works. At the Government works at Vöröspatek, and at the works of the Ruda Company at Brád, the ore is treated in Tyrol amalgamation mills, and at Vulkoj an American stamp battery, with Frue vanners, has been erected. The cost of stamping at Vulkoj amounts to 6*s.* per ton. In recently designing a mill for this district, the Author selected for comminuting the ore the Jenisch falling-ball mill, a machine that has been found to answer admirably for pulverizing basic slag. He is thus enabled to treat 30 to 40 tons of ore in

twenty-four hours with an expenditure of 6 to 8 HP. With the pan amalgamators employed, he has succeeded in reducing the total cost of treatment to 1*s*. 4½*d*. The cost of treating a ton of ore by the different methods that have been adopted in Transylvania is approximately as follows:—

	s.	*d.*
Californian stamps	6	0
Wooden stamps and pan amalgamators. . .	3	0
American roller-mills	2	0
Ball mill and pan amalgamators	1	9
Peasant stamps	2	0

B. H. B.

New Mercury-Furnaces. By J. M. Madariaga.

(Revista Minera, Metalúrgica y de Ingeniería, vol. xl., 1889, p. 305.)

The ores of mercury and arsenic, smelted by the El Porvenir Company, Asturias, Spain, were until quite recently treated in intermittent kilns of the Idria type. The ore was piled in lumps, with a small quantity of fuel, on a hollow arch, and the smaller material was moulded into bricks and placed above, whilst a fire lighted on a grate below the arch caused the decomposition of the ore to commence. Several important improvements have recently been introduced by the Company, and at the present time, instead of intermittent furnaces, there are employed a continuous kiln for coarse ore; a channel-furnace similar to those employed at Almadén, and a double-retort furnace for powdered ore.

The arrangement of the double-retort furnace is indicated by three drawings (on the scale of 1 to 100) accompanying the original memoir. The chief point of novelty is that the discharging hole is partially open, so as to allow air to enter. This is done without any danger of the fumes escaping by means of the artificial draught produced by a trompe (falling-water ventilator). The retorts are of cast iron, and have a common hearth on which small coal is burnt. Every hour and a half, 110 lbs. of pulverized ore are introduced through the hopper, and in the two retorts 3,527 lbs. of ore are treated in twenty-four hours. When the ore is very rich, it is charged in small lumps, and lime is mixed with it if the proportion of mercury amounts to 15 per cent. For the condensation of the fumes, there are two large chambers, two smaller ones, a wooden compartment with water on the floor, and finally the tromp and the pipe conducting the gases to the chimney, where no trace of mercury can be detected. From the first chambers, 90 per cent. of the outturn is obtained, and from the second nearly all the remainder, for after a year's work not more than 2 lbs. of mercury was obtained from the wooden compartment. During the operation, a considerable quantity of the metal runs out through holes provided near the floor of the condensing-chambers. The loss in this furnace is less than 1 per cent., and the cost of smelting 1 ton of

ore is 4*s.* 3*d.*, a sum that might be considerably reduced by employing six, instead of two retorts. In twenty-four hours, the hearth consumes 727 lbs. of small coal, valued at 2*s.* 2½*d.* Thus, with this furnace the results are very satisfactory; and there is the advantage of obviating the necessity for moulding the ore into bricks, an operation that costs nearly 1*s.* per ton.

The continuous kiln (illustrated by four drawings on the scale of 1 to 100), is slightly conical in shape. It is 6½ feet in diameter above the grate, and 6 feet at the throat, where it is terminated by a spherical dome, in the upper central part of which there is the charging hopper. The kiln may be considered to be divided into two parts, the lower or hearth portion being 9 feet 4 inches in height, and the upper portion, or kiln proper, being 9 feet 10 inches up to the discharge-pipe, and thence to the top of the dome 2 feet 10 inches. The total internal height is thus 22 feet. The hearth forms a chamber smaller in diameter than the rest of the kiln. At 2 feet 10 inches from the ground is the grate, which is 3 feet 7 inches in diameter. The walls continue, with the same diameter, 2 feet 8 inches higher. Above this is a conical segment 1 foot 7 inches in height, the top of which is 2 feet in diameter, and on it is a cylinder 2 feet in height, covered by a spherical dome pierced with holes through which the products of combustion pass from the hearth to the kiln proper. The central aperture is protected by a conical cast-iron cap, in such a way that the gases can escape without allowing ore to fall into the hearth. The hearth-chamber has externally a conical form, and is furnished with an iron cover down which the calcined ore passes to doors at the base. All the internal portion of the kiln is constructed of firebrick, the lining being 1 foot in thickness. A tower, 2 feet in thickness, encloses the whole kiln, and is provided at various heights with apertures through which the progress of the operation may be observed. The discharge-pipe for the fumes is of cast-iron. It is 1 foot 7 inches in diameter, and 13 feet in length, and is placed with an inclination towards the condensing-chambers. On reaching these, it bifurcates so as to communicate separately with the two series. There are two condensing chambers to the right of the pipe, and two to the left. The adjacent chambers communicate by means of two rectangular apertures near the floor, which slopes towards each side of the chamber, and has a current of water flowing under it. These chambers are in communication with four similar smaller chambers placed at a higher level, and from these, four pipes conduct the gases to a large general chamber, whence they are conveyed to a chimney 100 yards distant, by the aid of a trompe, the water of which is also used for cooling the floors of the condensing-chambers.

The kiln treats 8·5 tons of ore in twenty-four hours. It is charged every seventy-five minutes with 976 lbs. of ore, and 4·89 lbs. of coke. The grate is only fired in cases of necessity, and when it is required to start the kiln. The calcination is very satisfactorily effected; for the discharged ore does not contain

more than 0·02 per cent. of mercury. The condensation is also satisfactory, thermometrical determinations made in March and April, 1889, having given the following results:—

—	March. ° Fahrenheit.	April. ° Fahrenheit.
First chamber	305	262
Second chamber	141	134
Third chamber	84	82
General chamber	66	66
Chimney	44	50
Exterior air	46	53

A test with a gold plate indicated the absence of mercury from the gases in the chimney. The trompe producing the draught consumes 1·1 gallon of water per second, or 15,256 cubic feet per day. The cost of treating 1 ton of coal is:—Labour, 10¼*d.*; coke, 1*d.*; charging and removing ore, 7½*d.*; interest on capital, 7¼*d.*; total, 2*s.* 2*d.* Allowing 2*s.* 3½*d.* for administration, repairs, &c., the cost of smelting 1 ton of ore is 4*s.* 5½*d.* The following are the results of the first three trials of this kiln:—

—	I	II	III
Days in operation	23	20	30
Tons of ore treated	91·14	169·96	243·60
Percentage of mercury in ore	0·428	0·785	1·420
Contents of mercury, lbs.	858·1	2935·2	7610·0
Coke consumed on grate, lbs.	6·96	7·08	2·86
Coke consumed in kiln, lbs.	5·95	2·86	2·32
Coke consumed, total, lbs.	12·91	9·94	5·18
Weight of mercurial soot, lbs.	3615·7	13·1	21·6
Weight of mercury from condensers, lbs.	491·8	2533·3	5585·1

On washing the soot obtained in these three trials, the residue was found to amount to 24,906·2 lbs. This contained 10·87 per cent. of mercury, and yielded 2,707·3 lbs. The accumulations of arsenical residues prevents the campaign lasting longer than in these three trials. The mercurial soot is mixed with coke, and moulded into bricks, which are smelted in the old Idria furnaces with a loss of 10 per cent. of mercury. The loss in the new kiln is calculated to be 8·126 per cent.

B. H. B.

A Regenerative Annealing-Furnace. By J. von Ehrenwerth.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, 1889, p. 477.)

At Mr. F. Bœsner's wire-works at Augustenthal, near Neuwied on the Rhine, a new form of annealing-furnace with regenerative firing has been successfully adopted for some time past. The furnace has two circular heating-chambers or pits, each taking a single cast-steel annealing-pot, standing upon a rectangular substructure containing the gas- and air-passages and regenerators. The latter are low oblong chambers, measuring about 12 feet in length, 4 feet in breadth, and 2 feet in greatest height. Only two are used in each pair of furnaces, the air alone being heated as the gas is brought hot from the producer. Above the roof of the regenerator is placed a block of fire-brickwork containing the heated air and gas-flues, and the burner, which is a narrow ring-shaped passage, terminating at the bottom of the heating-chamber, giving a body of flame that entirely envelopes the annealing-pot placed in the centre. The chamber, which is a little larger than the pot, is about 5 feet high, 4 feet in diameter at the top, a little broader at the bottom, and is covered with a loose iron lid kept gas-tight by sand-joints, having a central passage communicating with the second chamber. In starting the furnace, as soon as one of the chambers is brought up to a strong heat, both receive their charges, consisting of a cast-steel pot, weighing about 18 cwt., and containing 16 to 18 cwt. of hard-drawn wire. The flame, after heating up the first pot passes through the passage at the top through the second chamber and regenerator into the chimney, until the proper heat is attained. The current of air and gas is then reversed, the valve, a single fourway-cock, commanding both passages by a single movement, and the heating of the second chamber commences; the current of spent flame, which at first is notably cooler than the previously heated pot, is passed over the latter until their temperatures are about equalized, when the finished heat is removed, and a new pot is inserted. Three of these double furnaces, taking pots 3 feet in diameter, of the capacity given above, and a smaller one for 20-inch pots, intended for annealing rivets, have been erected in place of an older series of heating furnaces, and the first one has been at work for eighteen months. Each double furnace heats ten pots, or a total weight of 8 to 9 tons of wire in twenty-four hours, so that the heat lasts about five hours. The consumption of coal has been reduced from 12½ to 13 per cent. of the weight of the wire heated, which was required in the old furnaces, to from 7 to 9 per cent., giving from 28 to 45 per cent., or an average of 36 per cent. saving in fuel. The wear of the annealing-pots is considerably lessened, their duration having been brought up from 300 to 600 heats, while the labour of handling is considerably lightened

owing to the pots being drawn at a lower temperature than was previously the case.

The Author gives a design of a similar furnace adapted for reheating steel ingots, and considers that it might be used to advantage in furnaces for cementation and making malleable castings.

H. B.

Report upon Questions relating to the Employment of Explosives in Presence of Firedamp.

(Annales des Mines, vol. xiv., 1888, pp. 197–376.)

This is an exhaustive report of a special sub-commission appointed by the French government to determine the behaviour of the different explosives capable of use in mines in the presence of firedamp. The sub-commission was composed of eleven members, of whom Mr. Mallard was president. The report is divided into five chapters, preceded by an historical note, and followed by tables and appended notes. Chapter I. describes the apparatus and mode of experiment. Chapter II. Explosives freely suspended in firedamp mixtures. Chapter III. Explosives exploded in a closed vessel. Chapter IV. Mode of firing shot in the mine; and Chapter V. Conclusions.

The conclusions are as follow :—

1. Even explosives under water can inflame firedamp mixtures with air by means of the dust of the mine.

2. The greater number of known explosives are capable of igniting firedamp mixtures when exploded freely in the atmospheres. Among these explosives are dynamite, gun-cotton (either military or mining, particularly the latter), gelatine dynamite, and Paulille's ammonia dynamite.

3. It is, however, possible to find explosives which detonate at a temperature sufficiently low to avoid inflammation of firedamp mixtures, at least in the great majority of cases, when freely exploded in the atmosphere. Among the explosives experimented on which approximately fulfil this condition are: (1) The intimate mixture of 50 parts dynamite with 50 parts of cystallized carbonate of soda, or sulphate of soda with 10 eqs. water of crystallization, ammonia alum, and ammonium chloride. (2) Moulin-Blanc pyroselin powder. (3) Mixture of 20 parts dynamite, at 75 per 100, and 80 parts of nitrate of ammonia. (4) Mixture of 20 parts of gun-cotton titrating 173 c.c. nitrogen dioxide and 80 parts nitrate of ammonia. (5) Bellite, of which the composition is not known with certainty, and the experiments have not been sufficiently numerous. (6) Favier's explosive containing 90 parts of nitrate of ammonia, 10 parts mononitro-naphthaline, which appears to equal Bellite in security. It requires, however, further experiment.

4. Because of the complexity and variability of the phenomena

occurring during the detonation of explosives free to air, it will be prudent to avoid firing shots in the mine, even with charges considered the safest, at points where the mixture of air and firedamp is inflammable. The choice of explosives must be considered as diminishing danger, but not as absolutely suppressing it.

5. It is necessary to employ the explosives under conditions such as to develop from them the maximum useful work. Economy and security are in accordance to recommend this rule. To accomplish this the following conditions are necessary. The explosive must be rammed with care and the hole must be sufficiently deep. No void space must be left either in front, behind, or round the cartridge. The Bickford fuze must not be placed in contact with the explosive if it is used, and the dangers of the fuze are sufficiently great to make it desirable to replace it by some more certain mode of ignition.

The commissioners further remark that their conclusions led to abandoning the use of blasting-powder in mines where firedamp is known to exist, and even to place under suspicion ordinary dynamite, blasting-gelatine, ammonia dynamite, such as is actually manufactured. Of these, blasting-gelatine appears to be the most dangerous. The explosives which give greatest security are the binary mixtures of dynamite, gun-cotton, bi-nitrobenzine with nitrate of ammonia; but the best mode of manufacturing and protecting these mixtures from atmospheric moisture has still to be experimented on. The breaking up of the coal and rock by them also requires practical study. The commission recommend the government to prepare sample cartridges and issue them to mining engineers who may be willing to conduct practical trials with them in ordinary work.

To the main report is added a supplementary one dealing more minutely with the conditions of the explosion of firedamp, and in the conclusions it is stated that the temperature of inflammation of firedamp is 500° Centigrade, but it is necessary that the action of this temperature should be prolonged to produce ignition. Because of this fact, and the almost instantaneous mixture of the products of combustion with the atmospheric air which causes them to cool rapidly, explosives in which the temperature of explosion is less than 2,200° Centigrade are incapable of inflaming firedamp mixtures when detonated under normal conditions.

The hole, however, must be carefully tamped, as the greater the imperfection of wadding, the greater the danger, and free explosion in air is the most dangerous of all. In the supplementary report the experiments with binary mixtures are detailed minutely, and it is again stated that nitrate of ammonia is the best substance to be used in connection with the explosives. The reports are illustrated with figures of the apparatus used, and numerous Tables are given.

D. C.

Experiments on Atmospheric Electricity.

By Dr. LEONHARD WEBER.

(Elektrotechnische Zeitschrift, 1889, p. 521.)

The Berlin Society of Electricians commissioned the Author to investigate experimentally the electrical condition of the atmosphere in various states of the weather. Three reports have already been made, of which the last dealt with the variation of the potential of the air with increasing elevation when the weather was clear, whilst the present report deals with the same subject when the sky is clouded. The Author finds that on clear days the potential rises with the height of the point of observation from the surface of the earth. He accepts Peltier's theory, according to which the earth contains a negative charge of electricity, and he finds that the potential V of a point *h* metres above the surface of the earth is related to the potential V_1, of the earth itself, according to the equation $V_1 = -\frac{dV}{dh} R$, R being the radius of the earth. The potential found for points 350 metres above the surface of the earth was 96,400 V, and the mean value of the differential quotient was found to be 275 V per metre altitude. From these figures he deduces the potential of the earth as $V_1 = -1 \cdot 72 \times 10^9$ V, or, in electrostatic measure, $V_1 = -5 \cdot 8 \times 10^6$ C.G.S. units. The charge of the earth is in electrostatic measure $- 3 \cdot 7 \times 10^{15}$ units, and the density is $- 0 \cdot 00072$ units per square centimetre for smooth portions of its surface. For prominent points, such for instance as the top of the Eiffel Tower, the density is very much greater, and drops of water or other small particles of matter coming in contact with such points will receive a negative charge and be repelled with measurable force. The Author next assumes that there is electric radiation between bodies of different potential analogous to the radiation of heat between bodies of different temperatures, and inclines to the belief that such radiation may even take place between heavenly bodies. On these suppositions he finds that negative electricity is conveyed to the earth from the sun by radiation, whilst the earth dissipates constantly an equal amount into space. The highest and lowest parts of clouds, and the particles of matter floating in the atmosphere are most instrumental in the process of radiation, and the dust particles floating in the lower regions of the atmosphere assume a negative charge which they give up to ascending particles of vapour. Clouds may be considered as conductors, the lower side being positively, and the upper side negatively electrified. The total charge may be positive or negative, according to circumstances, and the Author thinks it probable that generally the former will be the condition of snow-clouds, and the latter that of rain-clouds. When a cloud of considerable vertical extent is sheared horizontally asunder by the action of air currents, there are formed two clouds

of opposite charge, which, if passing in succession through the zenith, give rise to the rapid changes of potential often observed during thunderstorms. In confirmation of these views the Author gives a series of Tables, containing the results of experiments made during 1888 with balloons and kites, the altitude varying from a few metres above the surface of the earth to about 400 metres.

G. K.

New Type of Alternating-Current Motor. By F. J. Patten.

Paper read before the American Institute of Electrical Engineers, New York, Sept. 10, 1889.

(The Electrical Engineer, New York, 1889, p. 424, 6 Figs.)

The Author describes a new type of motor for alternating currents designed by himself, and expresses the problem to be solved thus:—

1. A machine that will start itself, independently of the speed of the generator or number of alternations of current per unit of time.
2. A machine that has but one direction of rotation, and cannot reverse under any conditions of current alternation.
3. A machine that is not necessarily synchronous with the generator, revolution for revolution.
4. A machine in which reversals of current-direction do not produce corresponding reversals of magnetism in any iron part when the machine is in motion, at its normal speed and maximum efficiency.
5. A machine of simple form, having an ordinary continuous wound armature revolving in a single or two-pole field.

If a Gramme dynamo of the ordinary type be used as a motor, and a direct current supplied to the brushes, then the armature becomes polarised in a constant direction, and will turn in a constant direction, supposing the polarity of the field-magnets to remain constant; but if the continuous current be replaced by an alternating current, then the polarity of the armature, and therefore the tendency to rotate, is reversed with each alternation of current, supposing the field to remain constant; but it will be noted that the motion would be in the same direction still if the field were reversed by the same reversal of current. If, however, the field remain constant, and some method of reversing the brushes at each reversal of current be found, the polarity of the ring would remain constant; it is impracticable to reverse the brushes, but the same effect can be produced in the following manner. In an ordinary Gramme ring, the point between two coils is joined to the collector-bar immediately under it; but if coils 1, 3, 5, 7 . . . be joined up in the usual way, and coils 2, 4, 6, 8 . . . be joined to the bar diametri-

cally opposite to the usual one, and we make the supposition that the ring shall turn through an arc equal to that covered by one bar of the collector during each alternation of current, a constant polarity will be maintained at the upper and lower points of the ring, without causing the brushes to change position mechanically. Its tendency to motion, then, in a constant field, would always be in the same direction.

The fundamental principle which underlies the construction of this type of machine is that, "The poles of any closed circuit may be maintained constant with an alternating current by causing opposite impulses to traverse the circuit in opposite directions." In order to obtain a shunt-current for the field-magnets, another collector is supplied, to which the ring is coupled up in the usual manner; and from the bars of this collector the connections are made to that just described, and by this means a constant field is obtained, and a constant polarity of ring, so that a constant direction of rotation is secured, provided the ring moves at such a speed that the brush touches the next collector-bar at each change of direction of current. Supposing that the machine does not move at such a speed as to fulfil the above requirement, then the polarity of ring and of the field both change together, and the machine becomes simply a direct-current machine on an alternating circuit, with a tendency always to rotate in the same direction. Assuming the machine to be self-starting, it will constantly gain in speed until the condition is fulfilled of one segment passing the brushes at each alternation, and it then becomes a synchronous alternating motor. The current then produces no reversals of magnetism, and there is a true alternating current in the armature circuit—producing, however, no reversal of armature polarity—and a current of constant direction in the field-magnet coils. Under these conditions the motor is self-regulating, moving at a constant speed and with a maximum rotary effort. It is not, however, essential that one bar should pass the brush at each alternation, as any number may be caused to do this, depending upon the speed required, and the number of coils upon the armature.

Thus groups of three coils may be treated as one coil; and supposing there were, say, twenty-four bars, then the machine would make one revolution for every eight alternations of current, and if connected to a circuit with 16,000 reversals per minute, its normal speed would be 2,000 revolutions per minute; and with forty-eight segments, in groups of three, it would be 1,000 per minute. There are blank segments insulating the groups of the inner collector, which are connected to the extremities of a rheostat which is placed inside the commutator, and is designed to offer a path for the alternating current, such as there may be, and prevent its absolute rupture at the period of change from one group of segments to the next; they also serve an important purpose in preventing a dangerous short circuit, which would be occasioned by the inner brush bridging two groups of segments oppositely connected. It follows as a matter of course, that, as the machine starts as a direct-

current motor connected in an alternating circuit, rapid reversals of magnetism will at first be produced in all the iron cores; and these should be made of laminated iron, to prevent undue loss by heating at starting.

E. R. D.

The Distribution of Electricity by the Constant-Current System.

By Alex. Bernstein.

(Electrotechnische Zeitschrift, 1889, p. 506. 7 Figs.)

Of the two systems of distribution, viz., that by means of constant current, with a varying electromotive force, and that by means of a constant electromotive force, with varying current, the Author gives the decided preference to the former. In this system, supposing glow-lamps to be used for lighting purposes, they are all arranged in series, the carbons being short and straight, and suitable for a current of 10 amperes, with a difference of potential at the terminals of each lamp of 6 volts, in the case of glow-lamps using the same number of watts, and working in parallel off leads, with a constant difference of potential between them, the usual type would be 100 volts, with a current of 0·6 ampere, but with such lamps the cross section of the main leads would need to be thirty-six times that required for the former kind, allowing for the same loss of power.

Another advantage is that, with the constant-current arrangement the difference of potential between any two points in the lamp circuit which might be touched at the same time by a person is very small, whereas with the parallel system the whole difference of potential may exist between two points close together. At first sight it would appear almost impossible to maintain a constant current in a circuit where the resistance must vary so frequently by lighting or extinguishing lamps, the electromotive force must be made to vary along with the varying resistance, and this may be done by varying the strength of the magnetic field, or by shifting the brushes. Neither of these appears to the Author to be at all satisfactory, and his method is to cause the speed of rotation of the armature to vary proportionally to the outside resistance. A series-wound dynamo is used, driven either direct or by belting, from a steam-engine, unprovided with the usual centrifugal governor. When the number of lamps in use is great, the speed of the engine and dynamo is high; but as the number is diminished so the speed falls. Supposing that at a given speed the dynamo is producing the proper current, with a certain number of lamps in circuit, this corresponds to a certain average steam-pressure acting on the piston; if now more lamps be lit, the outside resistance rises, the current falls, the dynamo turns more easily, and the speed of the engine rises until such a speed is reached that the balance is again restored; if a number of lamps are cut out, the speed in a

similar way falls. As the boiler-pressure cannot be kept perfectly constant, the Author has devised an electro-mechanical governor, arranged as follows: Upon the throttle-valve spindle is fixed a wheel, while at a point slightly below the centre of the wheel is fixed a small pulley, with three grooves, driven by a cord from the engine-shaft, and driving two small pulleys, one on each side of it, in opposite directions, by means of one crossed and one open cord; the two latter pulleys revolve on studs fixed to a lever, which rocks upon the stud carrying the middle one, and has a long end which is controlled by the action of a solenoid, the coils of which are in the main circuit; by the action of the solenoid either one or other of two friction-rollers, attached to the small pulleys, are drawn into contact with the wheel on the throttle valve spindle, and as they revolve in opposite directions so the valve is closed or opened; all the work is therefore done mechanically by the engine, and is merely directed by the electrical apparatus.

In the case of a dynamo used for parallel working, the speed must be kept constant in order to obtain a constant electromotive force, and the machine only reaches its maximum efficiency with the maximum load, for with a given boiler-pressure there is always one grade of expansion which gives the least coal-consumption. In the constant-current system, as above described, this grade can always be assured and the number of revolutions alone changed, so that the dynamo works as economically with half or a quarter of its maximum load as with full load. Another essential advantage in the series arrangement is that the necessity for fuzes is done away with; it often happens, in parallel working, that owing to a fuze being a little too delicate, a whole group of lamps is suddenly extinguished; the attendant hastens to put matters right, and may temporarily close the circuit with ordinary wire, which, if forgotten, might lead to a fire or to burnt-out lamps. Lamps for parallel working cannot be pushed to the extremes of high potential and weak current. Similarly, lamps for series working are limited to moderate current, and the Author has found 10 amperes to be most suitable. The quality of the surface of the carbons used in the lamps is very important, a smooth, highly-polished surface giving a much better efficiency than a dull, rough one; the carbons used are tubular, and are of such a size that they can be well polished, whereas this is quite impossible in the case of the long, fine threads used in the high potential lamps.

The Bernstein type of lamp is then described, with its special holder, which effectually prevents the circuit being left open when the lamp is not in use. The Author mentions 1,500 volts as the electromotive force he prefers to use, and then goes on to describe a transformer for use on a constant-current circuit in cases where it is advisable to divide the lamps into numerous series groups, as in town-lighting. The transformer consists of a motor and dynamo on the same axis, the motor driven from the central station by a constant current, and driving the dynamo which supplies a constant current to the circuit of lamps in series in the house. The trans-

formers are in series in the main circuit, and the revolutions made vary with the number of lamps lit, so that it is as economical at half-load as at full-load. The Author, in summing up, puts forward the advantages thus: (1) The practicability of lighting from distant central stations, which thus may be outside the town; (2) the economical working of the steam-engines from the fact that the same grade of expansion can be always used, a change of load being followed by a change of speed only; (3) simplicity of working; (4) cheapness of leads in streets and houses, and the diminished loss of power; (5) security from fire by absence of over-heating; (6) greater efficiency of the lamps.

E. R. D.

The Application of Electrical Transmission of Power at Bourganeuf. By Marcel Deprez.

(Comptes rendus de l'Académie des Sciences, Paris, vol. cix., 1889, p. 455.)

The Author first calls attention to the partially successful experiments on electric transmission of power between Paris and Creil which he made in 1886, and which demonstrated that 80 HP. could be transmitted when 165 HP. was being absorbed by the generator. In these experiments a pressure of 9,000 to 11,000 volts was used, and the failure of completely satisfactory results was attributed to the improper construction of the connecting cable, to defects of organization, and want of experience now available.

This year, however, the authorities of the town of Bourganeuf decided, if possible, to utilize the power of a waterfall on the Maulde, situated 1,100 yards from St. Martin-le-Chateau, and 8¾ miles from Bourganeuf, and the work was entrusted to the Société pour la Transmission de l'Électricité engineered by the Author. The fall utilized is about 100 feet, and develops 130 HP. in a horizontal turbine making 150 revolutions per minute.

The generator is a high-tension dynamo having two armatures on the same shaft in series with one another, of the form known as the Deprez model.

The electrical details of each armature are as follows:—

Resistance 2 ohms, diameter of wire 2 millimetres, allowing for the armature a total current of 35 amperes. The machine is separately excited, the magnets absorbing 90 volts 20 amperes, rather more than 2 EHP.

The line is double (out and return wires) composed of bare silicon bronze wire 5 millimetres diameter (about No. 6 B. W. G.), carried on porcelain insulators, giving an insulation resistance practically infinite even after prolonged rain. The total resistance of the line is 23 ohms.

The motor is identical with the generator, and is excited by part of the current from the dynamo used for the illumination of

the town, whilst to start the motor the current from a set of accumulators is used. The actual lighting machines are Gramme dynamos. Experiments with an artificial line having a resistance of 25 ohms gave the following results:—

Electromotive force at generator terminals 3,550 volts, current 20 amperes, the electromotive force of the lighting machines being 115 volts, and the current 376 amperes; taking the efficiencies of the low tension dynamos at 80 per cent., and the high tension machines (as experiment showed) at 90 per cent., this experiment proved that 60 HP. could be developed at Bourganeuf, by an expenditure of 100 HP. at St. Martin.

The actual working of the machines has proved admirable. The regulation is effected by a pure water liquid resistance, and by a code of signals from the motor attendant to the attendant at the generator station. In a month there was only one stoppage of the generator, and three of the motor, principally due to the inexperience of the enginemen. Particular precautions have been taken to avoid damage to the machinery from lightning discharges from the line, which appear to have been successful, but the methods adopted are not described by the Author.

Ll. B. A.

The Miot Magnetic-Induction Meter. By E. Dieudonné.

(La Lumière Electrique, 1889, p. 510, 4 Figs.)

The ordinary method of testing magnetic fields with a ballistic galvanometer and a small test bobbin is not sufficiently rapid for ordinary workshop use, and is subject to a number of errors. It is well known that any flexible conductor placed in a magnetic field across the lines of force tends to embrace as large a number of such lines as possible, and when such conductor is a liquid contained in a tube, it produces a pressure upon the interior of the tube proportional to the intensity of the magnetic field and to the current which passes through it. Mercury is used for the purpose, as it is the only liquid conductor which is not electrolyzed by the passage of the current. If a flat thin tube be used, having a long tube of fine bore in connection with it at right angles, then when the flat part is placed in a magnetic field, so that the lines of force pass through it, the mercury rises in the fine tube, and so may be made to register the strength of the field. In the instrument itself the flat tube is bent in a U shape, and the fine tube rises between the legs, the three ends are connected by short india rubber pipes to three tubes fixed to a board, the connections for the current are made to the side tubes so that the current passes down one leg of the U, through the mercury and up out of the other; the middle one swells into a ball into which the mercury rises a short distance, the remainder being filled with a light liquid such as alcohol, and this rises in an exceedingly fine graduated tube like a

thermometer, greatly magnifying the movement of the mercury. The thin flat tube is only about 0·03 of an inch thick, so that it can be inserted in the narrowest interpolar space; this form is not used with more than two amperes of current, and is for exploring fields where the intensity exceeds 400 C.G.S. units per square centimetre.

A larger instrument is made with a flat tube about 0·1 of an inch thick, suitable for a current of four amperes, and with this fields of an intensity of 50 C.G.S. units per square centimetre can be registered. In order to calibrate the instrument the tube is placed in a uniform magnetic field, alongside a wire of known length hung from the arm of a balance; the same known current is then passed through instrument and wire, and it is found that a certain weight must be put in the scale to maintain equilibrium; from these data the law of the instrument can be determined.

E. R. D.

The Electric Lighting of the Townships of Dieulefit and Valreas.

(Centralblatt für Elektrotechnik, 1889, p. 47.)

The townships of Dieulefit (Department Drôme) and Valreas (Department Vaucluse) in the south of France are lighted electrically by electric power generated at Béconne upon the Lez, a small tributary of the Rhone, situated 8½ miles from Valreas, and 3 miles from Dieulefit.

The stream feeds a reservoir sufficient for 1,200 HP. hours, about 800 HP. hours being sufficient for the lighting per day. The total fall is 80 feet, and the water is led by a pipe 30 inches in diameter to two horizontal turbines of 50 HP. each, making 180 revolutions per minute. Each turbine drives a Zipernowsky alternator of 2,000 volts 12 amperes, and an exciting dynamo giving 80 volts 30 amperes. Each town has its own turbine and dynamo, and one complete spare plant acts as a reserve for either. The speed is regulated by a centrifugal governor controlling the water supply.

The lighting is effected by transformers, and as at full load about 180 volts drop of pressure takes place over the line it is necessary to alter the exciting power on the alternators in order to keep the pressure at the further end constant. This is effected by an automatic regulator arranged as follows. In the main circuit is a transformer whose secondary is connected direct to a solenoid on the automatic regulator. This regulator consists of a float in water carrying at the top a vessel full of mercury into which dip the terminals of a series of resistance wires, these wires being of different lengths, so that, as the float rises or falls with the variation of current in the solenoid, the resistance in the circuit of the exciting current is altered.

The line is composed of bare silicon bronze, in the case of the shorter line 2·5 millimetres thick, and larger for the longer line. These are carried on porcelain insulators on posts. Each town has telephonic communication with the generating station. The transformers have a ratio of 18, from 1,750 volts in the primary to 95 in the secondary. The transformers are fixed in sheet-zinc cases outside the houses, and the secondary wires are carried on insulators outside the fronts of the houses, being also bare wires, and from these the subscribers' wires are tapped and carried in wood casing into the houses.

Owing to the extended area over which the lights are used in Dieulefit, nearly 2 miles separating the first from the last, the transformers which at Valreas are in parallel in groups of three are here coupled in series. At present in Valreas nine, and in Dieulefit six, transformers are at work, though each alternator is capable of working twelve transformers.

Ll. B. A.

Electricity on the Boston Street Railways. By H. M. Whitney.

(The Electrical Engineer, New York, 1889, p. 454.)

The Author states that on July 6th the electric line from Harvard Square to Arlington was opened, and the quickest time on record for horse-cars, thirty-five minutes, had now been reduced to twenty minutes, schedule time. In making the change from horses to electricity it would be necessary to include the whole system. The electrical centre of Boston, inside of Charles River, was at Pleasant Street and Shawmut Avenue. As the travel increased, the electrical centre would be coincident with the Hinckley Locomotive Works property, which the company had just bought as a power station. For twenty-five years to come, every electric car inside of Charles River, including South Boston, could be economically run from that station. The working of the cars would need, at no distant day, 10,000 HP., costing, in a large plant, about £20 per HP. A good double motor cost £600, and a single motor £400. They were running to-day between seven hundred and eight hundred cars, and, if the experience since electric cars were introduced is any criterion, they should need many more immediately. It would be necessary to issue £90,000 of new stock in order to supply wire, poles, new equipment, and new track. The present capital invested in road, rails, cars, horses, and equipments represented £2,324,000. The steady, regular increase was 10 per cent., but if the service is increased 10 per cent., the number of horses, cars, and general equipment would have to be increased in the same proportion. Electricity had been in use on the Arlington line for seventeen days, for the same time last year the receipts were £542, the receipts for this year £1,255, an increase of 150 per cent. On the Brighton line the total receipts for June last were £885,

for June this year £1,772. The time from Arlington to Harvard Square, 4 miles, is twenty minutes, equal to 12 miles per hour, while the average speed on the elevated roads, in New York, is only 10·89 miles per hour. The company expected to run 15 miles per hour, and had seven hundred and seventy-six cars, at a cost of £200 each, and it would cost £20 each to turn them into electric cars. The average cost of motive power by horse for the past six months is 5*d.* a mile, which does not include drivers, starters, conductors, and repairers of track. From experience on the Allston road, with the disadvantages of a faulty conductor and the power station being too distant, the cost for fuel to supply current is only ¾*d.* per car-mile; while the cost of power, engineering, engineers, and all other expenses amounts to rather over 1⅓*d.* per car-mile. The estimated cost of taking care of the motors and overhead line is 1¼*d.* per car-mile, so that working by electricity would lead to a saving of 2⅓*d.* per car-mile.

E. R. D.

The Magnetic Permeability of Soft Steels. By GEORGES HENRARD.

(La Lumière Électrique, 1889, vol. xxxiii., p. 593.)

Some dynamo builders having decided to use cast steel for the field-magnet cores and frames of their machines, the Author made experiments at the Montefiore Institute, Liége, in order to find steels sufficiently permeable to be employed for the purpose. The apparatus used was one described lately in 'La Lumière Électrique' by himself and Mr. Melotte. The tests were made on specimens of steel made at Angleur, obtainable of all degrees of hardness. The most permeable are very cheap; all could be cast, and welded; and No. 6, which costs 7*s.* 6*d.* per cwt., is softer than ordinary commercial wrought-iron, the carbon contained being only 0·1 to 0·3 per cent. A specimen of wrought-iron No. 4, of very good quality, and a specimen of malleable cast-iron from the Herstal foundry, were tested for comparison; the cast-iron was a mixture of grey and white pig, and had been decarbonized by heating along with sesquioxide of iron $Fe_2 O_3$. The Author states that, with a magnetic field of a strength equal to 240 C.G.S. units, the bar of malleable iron gave a specific induction of more than 15,000 C.G.S.; whereas Dr. Hopkinson, in a work published in 1885, gives 12,408 C.G.S. as the maximum for the metal, with the same field. Three Tables are given; the first for permeability, in which H is the strength of the field in C.G.S. units, and μ the permeability; the specific induction being therefore $B = \mu H$; the second gives the mechanical properties, and the third the chemical analysis. The permeability of a steel cannot be judged of by its percentage of carbon merely, as small percentages of other elements alter the results greatly. For instance, steel No. 5·5, which should be softer and more per-

meable than No. 5, gave a poorer result owing to having a greater percentage of manganese. All these steels have a high permeability, and another advantage is that it is not necessary to use ferro-aluminium in pouring them. From Table 1 the following numbers are extracted: for a field of 250 C.G.S. units the permeability was, for steel No. 6, 100; No. 5·5, 80; No. 5, 80; No. 4·5, 86; No. 4, 76; No. 3·5, 80; No. 3, 74. Wrought-iron, No. 4, 80; malleable cast, 60. The Author draws special attention to steel No. 6; and then gives the following tests for specific resistance at 68° Fahrenheit:—

Steel,	No. 6,	212 microhms per cubic inch.
„	No. 5·5,	365 „ „ „

E. R. D.

The Influence of the Rotation of the Earth on Moving Bodies.

By T. von Bavier.

(Zeitschrift des Vereines deutscher Ingenieure, 1889, p. 862.)

It has often been observed that in railway lines running north and south there occurs, in course of time, an appreciable displacement of the rails, always more noticeable on the right-hand side. This is, as the Author remarks, chiefly due to the effect of the rotation of the earth on its axis, the normal condition being that with a train travelling in such a direction and equally loaded there is a greater pressure on the right-hand side than on the left.

In N. latitude 51° a man weighing 165 lbs., running at the rate of 13 feet per second from north to south, sustains a horizontal pressure towards the east equal to 54 grains, which, acting at the centre of gravity of the body at say 3 feet 3 inches above the ground, necessitates an extra pressure on the right foot of 0·63 oz., in order to maintain the vertical position of the body. In going from south to north the proportion is the same; in the southern hemisphere the extra pressure would come on the left side. With varying directions the force is, of course, proportionately varied.

In the case of an express train, weighing say 400 tons, travelling northwards at the rate of 50 miles an hour, the extra pressure on the right-hand or eastern rail amounts to 501 lbs., the same pressure coming on the right-hand or western rail when travelling in the reverse direction. In more northerly parts the lateral force increases, reaching its maximum at the North Pole, in which region, in a case similar to the preceding, the extra pressure on the right-hand side would be 660 lbs. In the large ocean steamers the force is considerably greater; the side-pressure on the Inman liner "City of New York" being about 936 lbs. The tendency of this lateral pressure would be to drive the vessel (if on a northward or southward course) somewhat to the east, so that to keep on

a prescribed course requires a slightly-increased engine power to overcome the tendency to deviation. This increase is, however, not more than $\frac{1}{10,000}$. Such as it is, it is inappreciable on the east and west run between Liverpool and New York; but would be distinctly perceptible in a voyage to Buenos Ayres.

P. W. B.

The Law of Thermal Radiation. By W. Ferrel.

(The American Journal of Science, vol. xxx., 1889, p. 3.)

In this Paper the Author compares the formulas of the law of thermal radiation as determined by Dulong and Petit seventy years ago, and Stefan in 1879, and he also examines the experiments of Lehnebach, Rosetti, Schleiermacher, Graetz, Violle, Langley, and others. When H = the rate with which heat is radiated by a body from each unit of surface, τ = the temperature of the radiating body, m = the value of H at the temperature of $\tau = 0$. Then if $H = m\,a^{\tau}$ when $a = 1 \cdot 0077$ the formula expresses Dulong and Petit's law, which, however, is only true for empty space, and requires modification when the body is contained within a perfect enclosure. The Author compares Tables of the results of Dulong and Petit's experiments and Stefan's experiments, and remarks that although their expressions satisfy the rates of cooling equally well from 80° to 240° Centigrade, yet that little reliance can be placed from this fact upon deductions as to the rate of cooling in space. Among other matters the Author mentions Langley's deductions from his experiments at the Edgar Thompson Steel-works, near Pittsburg, that the solar heat radiation is about one hundred times greater than that of melted iron at a temperature of 1,800°, angular area for area. Calculating from this, and making the assumption that molten iron has the same relative radiativity as an equal portion of the solar surface, and correcting in the light of Dulong and Petit's and Stefan's laws, the Author estimates that the solar temperature is probably 5,933° Centigrade.

In conclusion, the Author remarks that it is necessary to have radiation experiments made at much lower temperatures than those of any researches yet attempted in order to arrive at the true value of the rate at which heat is radiated from each unit of surface at zero.

D. C.

INDEX

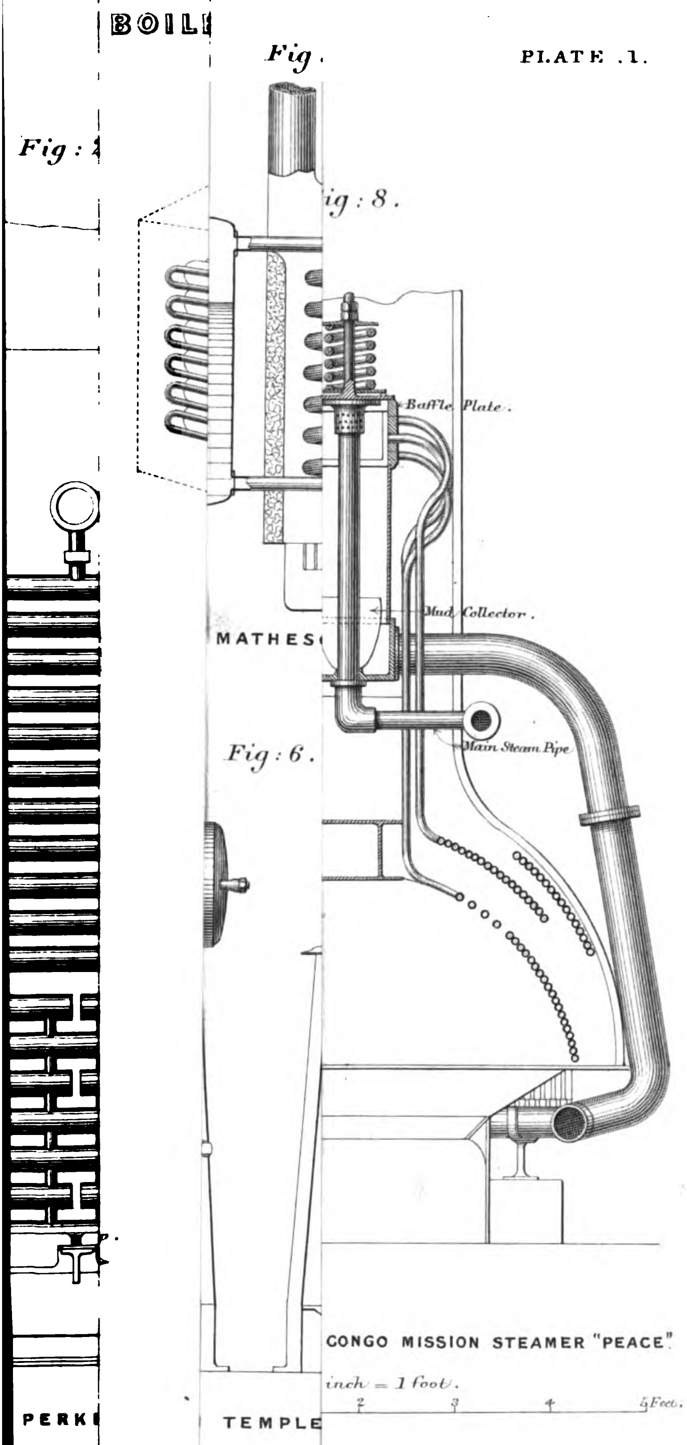
TO THE

MINUTES OF PROCEEDINGS,

1889-90.—PART I.

LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
STAMFORD STREET AND CHARING CROSS.

PLATE .1.



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KELL & SON, LITH. 40, KING ST COVENT GARDEN

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PLATE .1.

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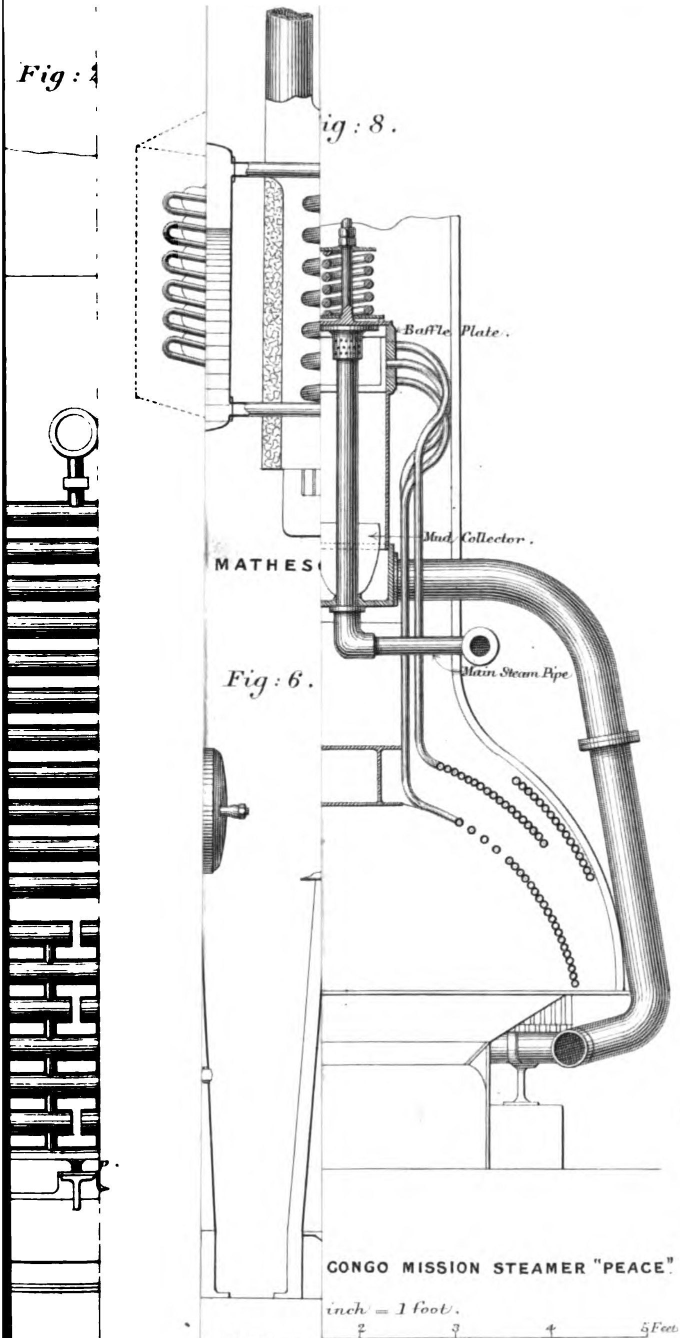

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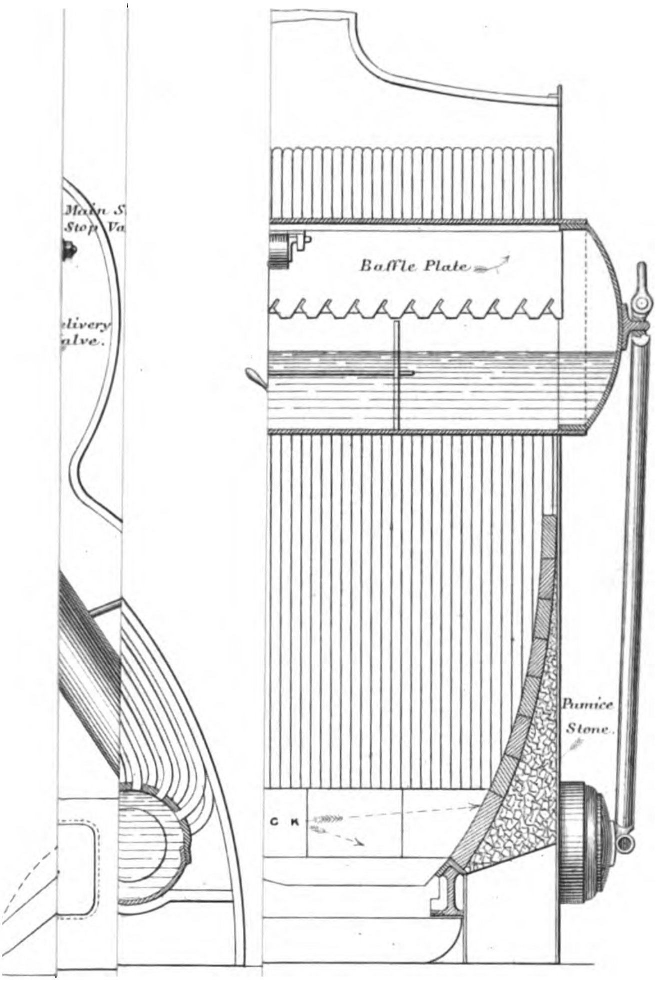

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TH KELL & SON LITH 40 KING ST COVENT GARDEN

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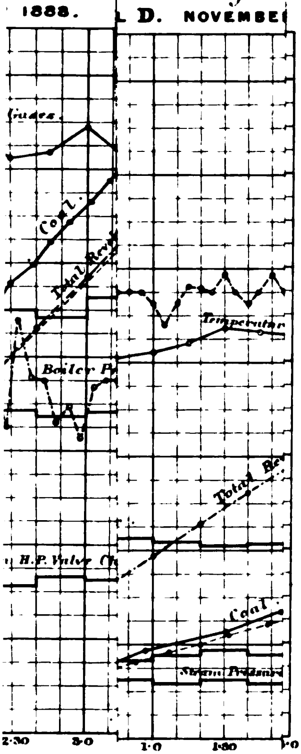

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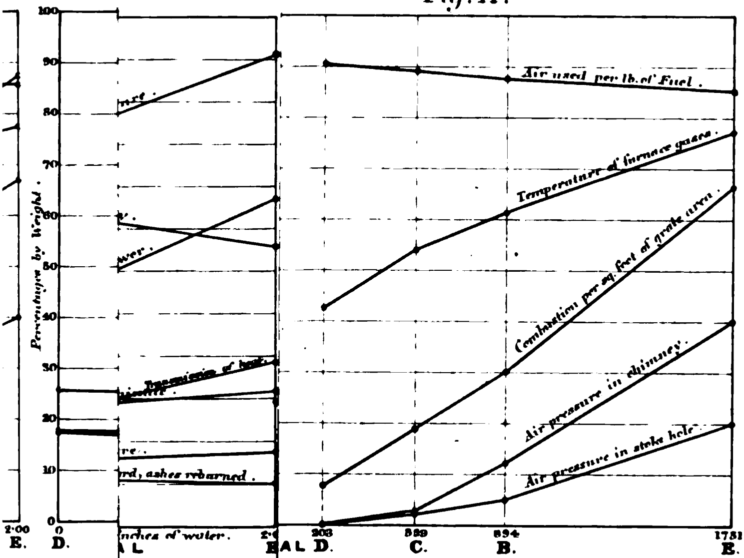

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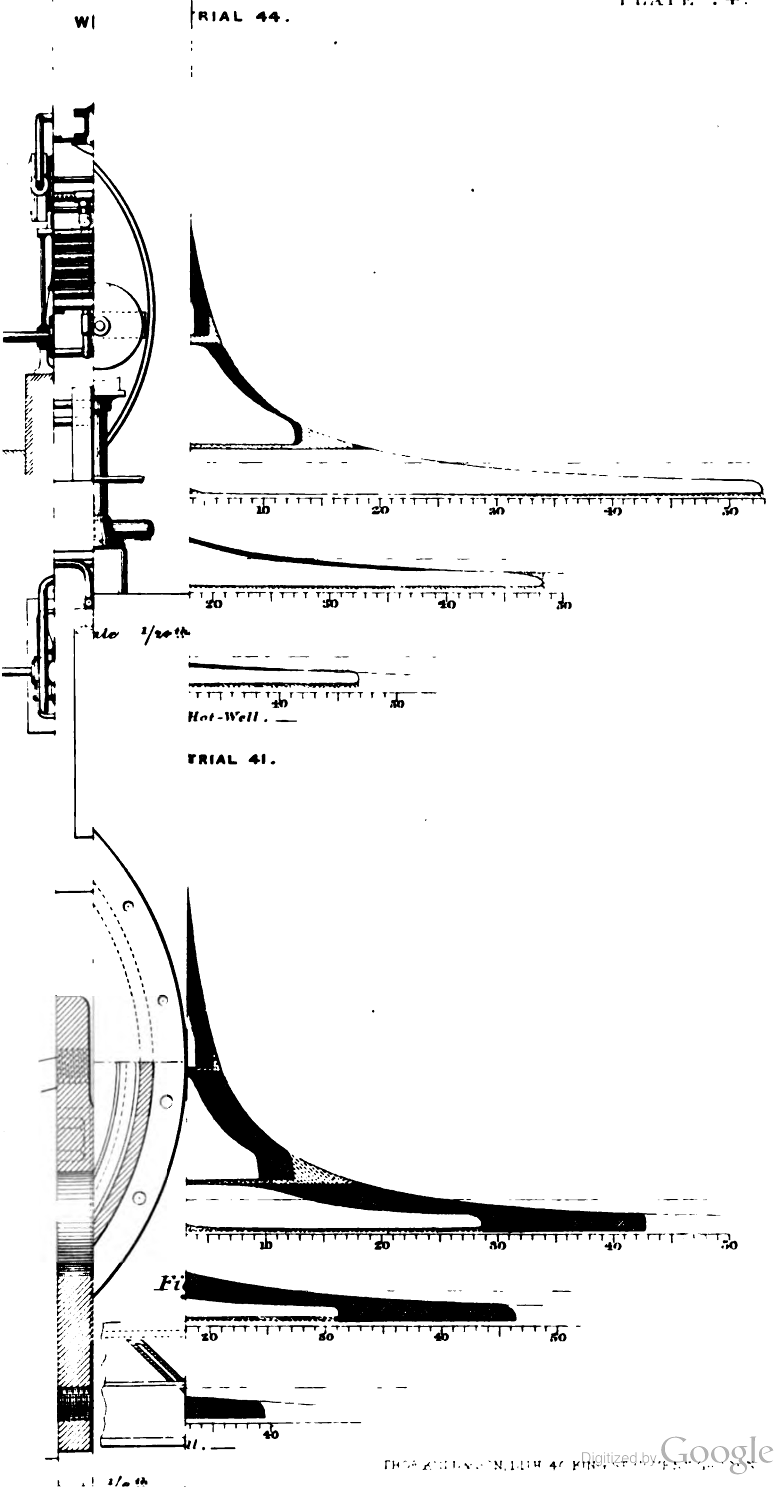
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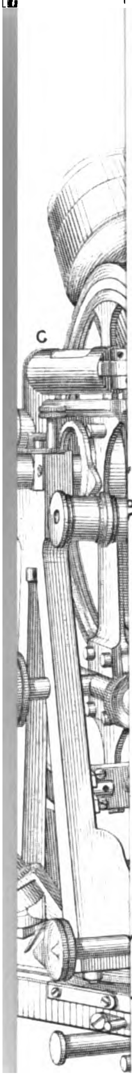

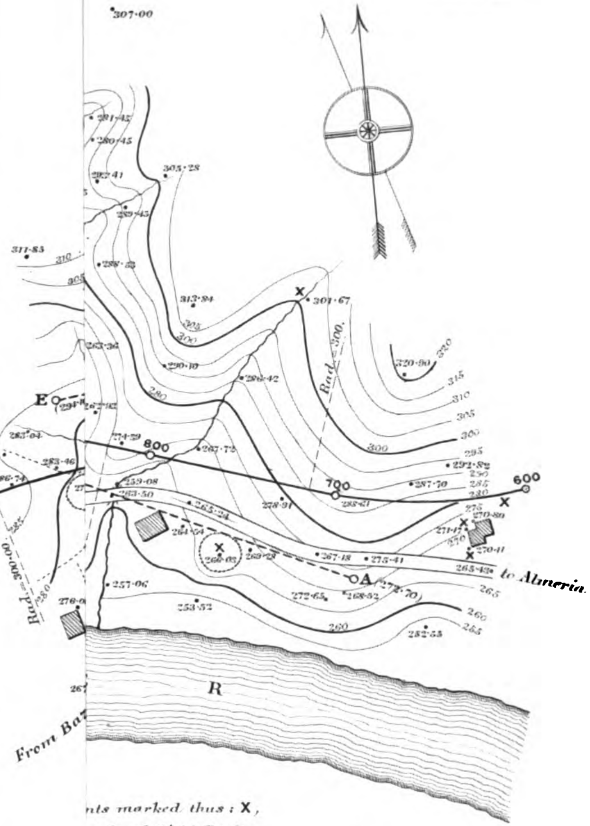

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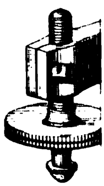

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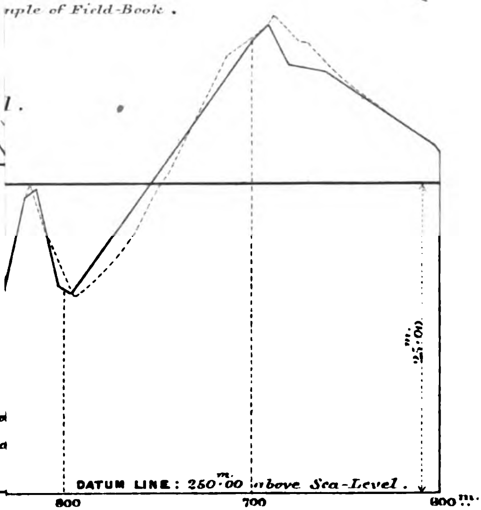

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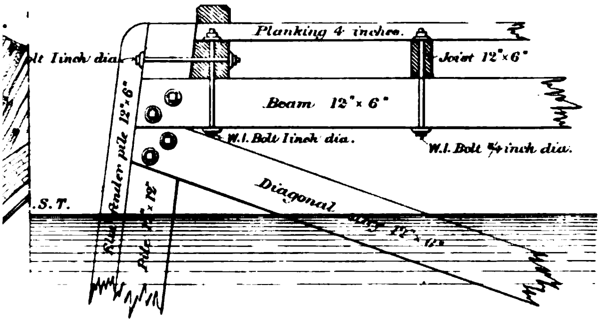

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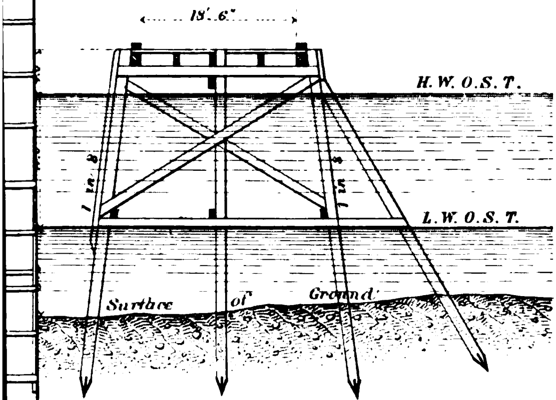

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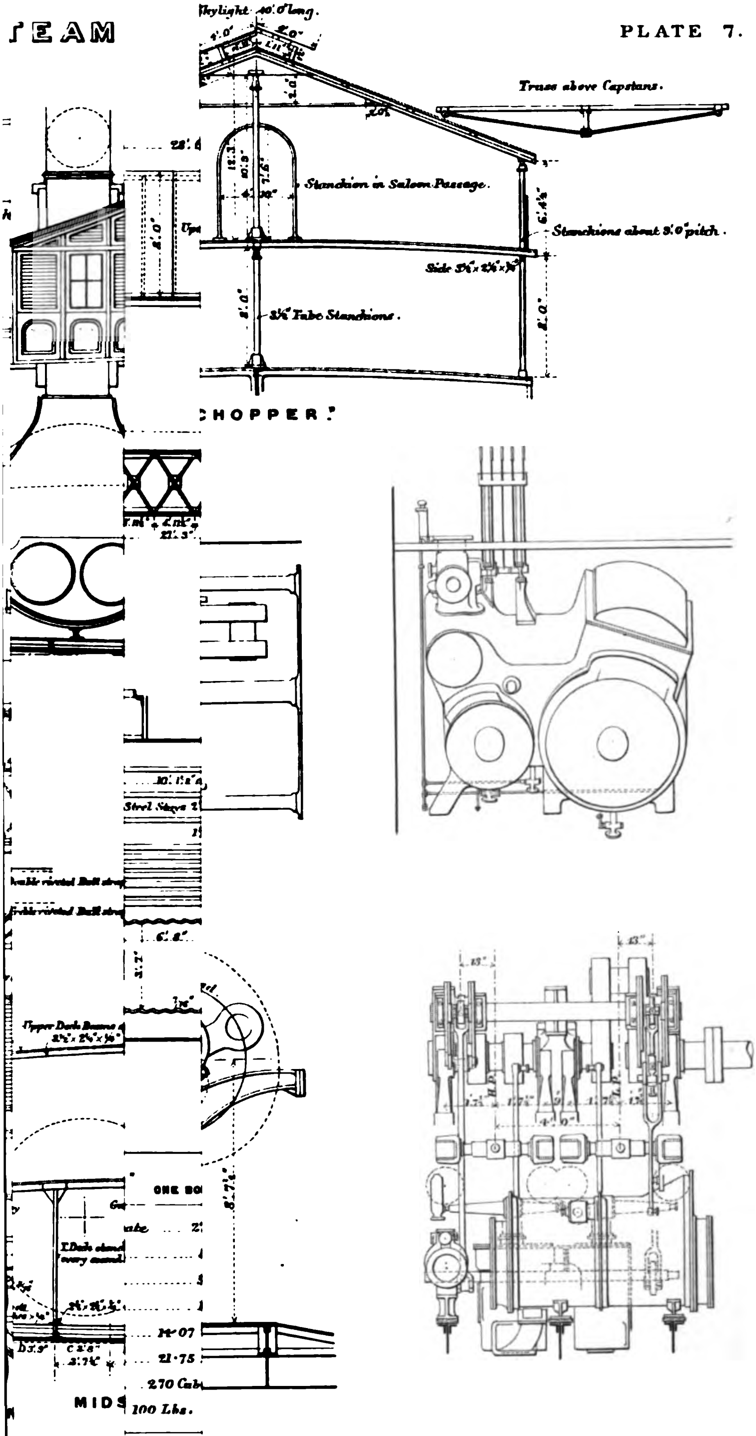
THOS KELL & SON, LITH. LONDON.



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